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Comparison of the Performance of Noise Metrics as Predictors of the Annoyance of Stage II and Stage III Aircraft Overflights

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ABSTRACT

Thirty audiometrically screened test participants judged the relative annoyance of two comparison (variable level) signals and thirty-four standard (fixed level) signals in an adaptive paired comparison psychoacoustic study. The signal ensemble included both FAR Part 36 Stage II and Stage III aircraft overflights, as well as synthesized aircraft noise signatures and other non-aircraft signals. All test signals were presented for judgment as heard indoors, in the presence of continuous background noise, under free-field listening conditions in an anechoic chamber. Analyses of the performance of 30 noise metrics as predictors of these annoyance judgments confirmed that the more complex metrics were generally more accurate and precise predictors than the simpler methods. EPNL was somewhat less accurate and precise as a predictor of the annoyance judgments than a duration-adjusted variant of Zwicker's Loudness Level.

1 INTRODUCTION

Part 36 of the Federal Aviation Regulations establishes noise emission limits for various weight categories of aircraft sold in the United States, and describes detailed procedures for measuring such emissions. The scale on which limits for aircraft noise emissions are expressed in Part 36 is the Effective Perceived Noise Level (EPNL). This noise metric was developed in the late 1950s, prior to the design and entry into service of most of the fleet of commercial jet transports serving civil airports today. Since noise produced by few aircraft heard in contemporary airport neighborhoods contributed to the development of EPNL, the continued reliability of this noise metric for an important regulatory purpose is a matter worthy of empirical study.

1.1 PURPOSE OF STUDY

The present laboratory study was designed to yield direct comparisons of the relative abilities of a variety of noise metrics to account for a set of judgments of the annoyance of recorded flyovers produced by current generation jet transports and other noise sources. Table 1 summarizes the classes of average (equivalent continuous sound level), maximum, and time-integrated noise metrics of present interest.

1.2 ORGANIZATION OF REPORT

Chapter 2 contains background information on the development of Perceived Noise Level and alternate measures of the loudness and annoyance of noises. Chapter 3 describes the procedures used to select test signals and data collection methods used in the subjective judgment experiment. Chapters 4 and 5 present study results and discuss certain implications of the findings. Conclusions may be found in Chapter 6. A Glossary is provided in Chapter 9 for the benefit of readers unfamiliar with some of the terminology of regulatory acoustics. Appendix A contains instructions to test participants and the informed consent form signed by each prior to participation in the study. Appendix B contains additional graphic and tabular material.

Table 1 Names and abbreviations of average, maximum, and duration-adjusted noise metrics evaluated in present study

Spectral Weighting or Calculation	AVG	MAX	Integrated Level
A-Weighted Sound Level	TAVA	MXMA[2]	ASEL
B-Weighted Sound Level	TAVB	MXMB	BSEL
C-Weighted Sound Level	TAVC	MXMC	CSEL
D-Weighted Sound Level[1]	TAVD	MXMD	DSEL
E-Weighted Sound Level[1]	TAVE	MXME	ESEL
Overall Sound Level[1]	TAVOA	MXMOA	OASEL
Perceived Noise Level	TAVPNL	MXMPNL	EPNL(NT)[3]
Tone-Corrected Perceived Noise Level	TAVPNLT	MXMPNLT	EPNL[4]
Perceived Level (Stevens)[1]	TAVPLS	MXMPLS	PLSSEL
Loudness Level (Zwicker)[1]	TAVLLZ	MXMLLZ	LLZSEL

[1] Non-standardized measures.

[2] The time interval used for maximum sound level, 500 ms, was between fast (125 ms) and slow (1000 ms), hence MXM[edium]A.

[3] EPNL without tone correction.

[4] Aspects of current calculations not in strict compliance with standardized definitions:

a) an averaging time of 0.5 sec (rather than 1 sec);
b) a reference time of 1 sec (rather than 10 sec).

2 BACKGROUND

Efforts to predict the loudness and annoyance of acoustic signals from detailed knowledge of their spectral content and other physical characteristics are among the oldest of psychoacoustic endeavors. Allen (1996) traces efforts to develop psychophysical measures of the loudness of sounds to Fletcher's studies in the 1920s. Schultz (1972) describes subsequent work dating from the 1930s to standardize frequency weighting networks and to develop additional noise metrics and rating schemes as predictors of the annoyance of environmental noise exposure. A large body of psychoacoustic research led to proposals in the 1960s and 1970s for an alphabet soup of metrics of the loudness and annoyance of individual noise events and cumulative noise exposure. Many of these metrics correlated more highly with one another than with annoyance.

Entry into commercial service of Boeing 707 transports in the late 1950s provided the impetus for creation of expanded families of metrics of the annoyance of individual and multiple aircraft overflights. By 1969, the U.S. Federal Aviation Administration had selected Effective Perceived Noise Level (EPNL) as the metric for aircraft noise certification in Part 36 of the Federal Aviation Regulations. This chapter sketches the development of Perceived Noise Level and alternate measures of the loudness and annoyance of noises.

2.1 DEVELOPMENT OF PERCEIVED NOISE LEVEL

Procedures for calculating the "perceived noise level" of sounds began with subjective judgment experiments conducted by Laird and Coye (1929), Reese and Kryter (1944) and Kryter (1948). This line of research sought to quantify putative differences between the loudness and the annoyance, noisiness and acceptability of acoustic signals. The results of these early studies of the relative noisiness of octave bands of random noise throughout the audible spectrum were eventually characterized in equal noisiness contours. This approach was explicitly patterned—even to the definition of a unit, the "noy," resembling the sone—after Fletcher and Munson's well known frequency weighting networks and Stevens' (1956) early loudness calculation methods.

Studies sponsored by the (then) Port of New York Authority in the late 1950s subsequently yielded a body of judgments of the noisiness of recorded aircraft takeoffs and landings (Kryter, 1959) as heard indoors, rather than judgments of meaningless bands of noise. Noisiness was defined in these test instructions by terms such as "objectionable," "disturbing," and "unacceptable." Kryter and his colleagues collected subjective judgments both by the method of individual adjustment (in which test participants were asked to adjust the level of one recorded aircraft flyover until it was as noisy as another), and by the method of paired comparisons (a forced choice method in which test participants were required to indicate which of a pair of flyovers was the noisier).

Initial comparisons of the relative noisiness of piston-powered aircraft (DC-7 and Constellation) and turbojet-powered aircraft (Caravelle, Comet, and B-707) revealed average differences in overall sound pressure level at the point of subjective equality of noisiness for the two types of aircraft as great as 15 dB. In other words, test subjects reduced the overall level of the jet aircraft flyovers by as much as 15 dB when they believed them to be equally annoying to the flyovers of piston-powered aircraft. The poor performance of overall SPL as a predictor of these noisiness judgments led to development of Perceived Noise Level (abbreviated PNL and represented symbolically as L_{PN}). PNL was calculated much as Stevens' Loudness Level, substituting equal noisiness contours for equal loudness contours.

The principal differences between loudness and noisiness contours were at the extremes of the frequency range, reflecting empirical findings that high levels of low frequency bands of noise were judged less annoying than high levels of high frequency bands of noise. Annoyance contours were thus drawn at higher relative levels at low frequencies than loudness contours, but at lower relative levels at high frequencies. Predictions of the judged annoyance of aircraft overflights made with the PNL metric varied by only about ±2 PNdB when jet flyover noise was judged as disturbing as piston-powered aircraft flyover noise.

PNL was further refined under NASA and FAA sponsorship to extend its usable frequency range and give consideration to the effects of the tonal content and duration of noise events. For example, Pearsons (1966) investigated the effects of duration and background noise on the perceived noisiness of sounds in annoyance judgments of aircraft noise recordings heard in a continuous background environment in an anechoic chamber. Results of this investigation indicated that the presence of background noise reduced the judged noisiness of an aircraft flyover.

Pearsons, Horonjeff, and Bishop (1968) subsequently investigated the annoyance of single, modulated and multiple tones mixed with noise. Subjects were asked to judge which of a pair of sounds (tones plus noise, or noise alone) was the noisier, or in some cases, louder. Test signals included both broadband and octave band noises, as well as single tones at 250, 500, 1,000, 2,000, and 4,000 Hz. Judgments were also solicited of the noisiness of amplitude and frequency-modulated tones at 500 and 2,000 Hz. Signals were also created with multiple tones, including 2- and 5-tone complexes with overall frequency spacings of 1/10, 1/3, 1, 4/3, and 2 octaves.

Pearsons *et al.* (1968) concluded, *inter alia*, (a) that modulated tones were not greatly different in judged noisiness from unmodulated tones (although a slight decrease in noisiness was observed at higher modulation rates); (b) that harmonically related and non-harmonically related multiple tones did not differ greatly in annoyance; and (c) that multiple tones were more annoying than single tones. The same issues were revisited a decade and a half later by Hellman (1982). Pearsons and Bennett (1969) investigated the judged noisiness of temporally and spectrally varying signals. PNL with tone (Sperry, 1968) and duration adjustments provided the most accurate predictor of judged noisiness.

Much other psychoacoustic study of the noisiness and annoyance of transportation noise was conducted worldwide during the 1960s and 1970s, exploring issues such as the influence of Doppler shift and background noise levels on the judged noisiness of test signals. Stevens, meanwhile, conducted an independent line of experimentation over many years that eventually produced a standardized (Mark 6) "loudness level" calculation based on either full or one-third octave band noise data. Believing that there was little difference between loudness and annoyance, Stevens later proposed Perceived Level as a compromise between PNL and LL, since be he concluded that one metric could adequately serve both purposes. The calculation procedure for PL employed straight line segment approximations (to a frequency of 1 Hz!) to simplify loudness contours for computer use. Although described in the literature, this metric has never been standardized. The current form of PNL required for aircraft noise certifications per FAR Part 36, Effective Perceived Noise Level (EPNL), is well standardized, and is based on calculations of tone-corrected PNL (PNLT) every half second during an aircraft overflight.

2.2 DEVELOPMENT OF OTHER NOISE METRICS

FAA's adoption of PNL constituted at least tacit endorsement of Kryter's view that annoyance differs from loudness in its relative tolerance of high levels of low frequency noise and intolerance for high levels of high frequency noise. This view has been consistently challenged by Zwicker and others, who have questioned whether annoyance should be viewed as anything more than duration-corrected loudness. Zwicker's work in the 1950s was not widely available in English, however, and did not become well known in the United States until it was summarized by Zwicker and Scharf in 1965. Zwicker continued active development of his model through the 1970s (*cf.* Zwicker, 1977), and it remains under development today by his successors (*cf.* Moore and Glasberg, 1995). Industrial applications of Zwicker's loudness computation model remain more common in Europe than in the United States even today, in part for non-technical reasons.

Zwicker's framework for modeling the loudness of sounds is considerably more analytic than the largely empirical approach taken by Kryter to modeling the annoyance of sounds. Zwicker's approach is also more sophisticated in a number of ways, since it permits explicit consideration of the level-dependence of loudness judgments, and takes account of the upward spread of self-masking of broadband noises. Since Zwicker's model proceeds from first principles, it does not rely solely nor even critically upon empirical data about matters such as the shape of equal loudness contours, the rate of growth of loudness with level at various frequencies, bandwidths of low frequency critical bands, the level of the internal low frequency noise floor, *etc.*, for its elaboration.

This has proved to be both an advantage and a disadvantage. On the one hand, Zwicker's model is readily modified as new data become available about model parameters. On the other hand, numerous suggestions for modifications to Zwicker's model since its initial standardization as ISO 532B, and the availability of several generations of (often poorly documented) software implementations of the model, have produced some confusion about the currency and replicability of loudness level calculations.

3 METHOD

This chapter describes the procedures used to make field recordings of aircraft overflights, the processing and calibration of these overflights for use as test signals, and the data collection methods used to determine points of subjective equality of annoyance among them.

3.1 FIELD RECORDINGS OF AIRCRAFT OVERFLIGHTS

Wideband digital recordings of overflights of commercial jet transports were made during approaches and departures at McCarran Airport in Las Vegas, Nevada and at Seattle-Tacoma International Airport near Seattle, Washington. Recording sites at each airport were chosen near locations designated for FAR Part 36 certification points: 3.5 miles from the start of takeoff roll for departures, and 1 mile from touchdown for approaches. Recordings were made with 0.5 inch electret microphones (Brüel & Kjær 4155) and a portable digital tape recorder (Sony D-10 Pro II DAT). The tape recorder was operated continuously for 2 hours at a time, during which observations of aircraft identifying features were noted and a time-display videotape recording was made for final identification of overflying aircraft. Control tower logs were used as available for further confirmation of aircraft types.

3.2 SELECTION OF TEST SIGNALS

High quality recordings of both approaches and departures were sought for each aircraft type measured. Preliminary selections of aircraft noise recordings were made by reviewing their A-weighted time histories and selecting those without overlapping aircraft noise and those that occurred at times of low ambient and wind noise levels. Final selections were made by careful listening to eliminate recordings in which extraneous, low level noises (*e.g.*, bird song, horns, trucks, construction noise, alarms, *etc.*) could be heard.

The digital field recordings were supplemented with older analog recordings from BBN and NASA libraries of aircraft overflights. Simulated noise signatures of overflights of future aircraft, including a takeoff and landing, were provided jointly by an airframe manufacturer and NASA. Table 2 describes the suite of signals selected for annoyance judgments. Table 3 lists identification numbers for test signals.

Table 2 Signals selected for paired comparison judgments.

SIGNAL SOURCE	ABBREVIATION		
Stage III Aircraft	**Landing**	**Takeoff**	
Boeing B737-300	733L	733T	
Boeing B747	747L	747T	
Boeing B757	757L	757T	
Boeing B767	767L	767T	
Boeing B777		777T	
Lockheed L1011	101L	101T	
McDonnell Douglas DC10	D10L	D10T	
McDonnell Douglas MD11	M11L	M11T	
McDonnell Douglas MD80	M80L	M80T	
McDonnell Douglas MD82	M82L	M82T	
Stage I and II Aircraft and Other Sources	**Landing**	**Takeoff**	**Passbys**
Boeing B707 (Stage II)	707L		
Boeing B727 (Stage II)	727L	727T	
Boeing B727 (Stage II)		72TF [long duration]	
Boeing B737-200 (Stage II)		732T	
Douglas DC7B (Stage I)	DC7L		
Douglas DC8(J) (Stage I)		DC8T	
Simulated Aircraft Noise(short duration)		SIMT	
Simulated Aircraft Noise Stage-X	ST5L	ST6T	
USAF B1B Flyover			B1BF
USAF F111 Flyover			F11F
Automobile			AUTO
Train			TRAN

Table 3 List of test signal identification numbers and corresponding test signals.

ID #	Abbr.	ID #	Abbr.
1	101L	19	D10T
2	101T	20	DC8T
3	727L	21	M11L
4	727T	22	M11T
5	72TF	23	M80L
6	732T	24	M80T
7	733L	25	M82L
9	733T	26	M82T
10	747L	27	SIMT
11	747T	28	ST5L
12	757L	29	ST6T
13	757T	30	707L
14	767L	31	AUTO
15	767T	32	B1BF
16	777T	33	DC7L
17	777T	34	F11F
18	D10L	35	TRAN

3.3 PROCESSING OF FIELD RECORDINGS INTO TEST SIGNALS

All selected signals were digitized with 16 bit precision at a rate of 30 kHz through a 12.5 kHz anti-aliasing filter and stored as files on disk for post-processing. The waveform files were edited digitally to limit signal durations to the portion of the complete overflight recording that would be audible above the intentionally-introduced background noise that was heard at all times that test participants were present in the anechoic chamber. The beginnings and ends of the edited waveforms were smoothly tapered and ramped to avoid production of onset or offset transients during reproduction.

The digital waveforms were then reproduced through a 16 bit D-A converter, programmable attenuator, house filter, and the remainder of the instrumentation chain used in the course of experimentation to create the sounds heard in the anechoic chamber by test subjects. Figure 1 shows the shape of the filter used to modify the spectra of overflights recorded outdoors to simulate indoor reproduction. All signals were measured at nominal presentation levels at the test participants' head position with a B&K Type 4155 (0.5") electret microphone and a B&K 2134 Sound Intensity Analyzer functioning as a real time spectrum analyzer. One-third octave band sound pressure levels between 25 Hz and 10 kHz produced by the spectrum analyzer were sampled every half second and stored as digital time history files. These files subsequently served as the basis for calculation of the various noise metrics summarized in Table 1.

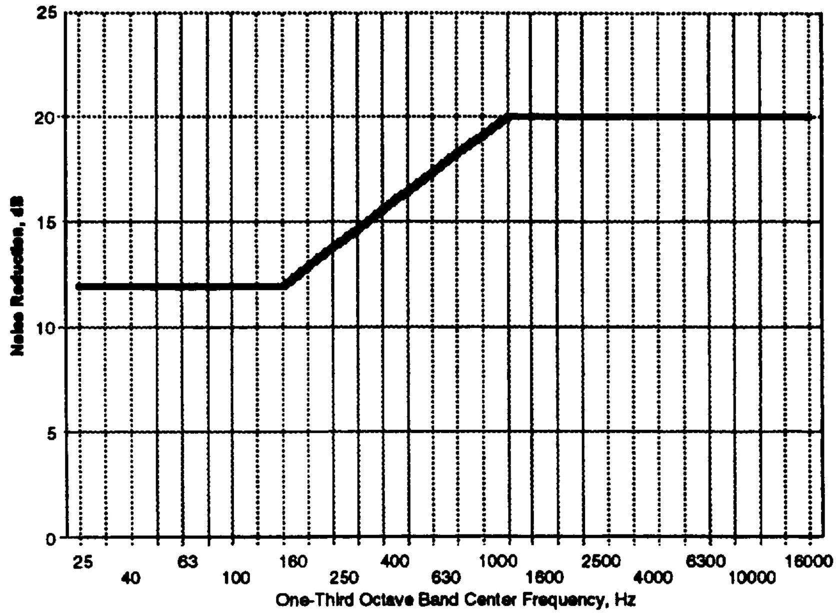


Figure 1 Response of filter used to approximate the noise reduction provided by a typical one-family frame house with windows partly open.

3.4 TEST SUBJECTS

Participants were audiometrically screened to within 20 dB of normal hearing (audiometric zero) over the frequency range of 100 to 6,000 Hz prior to testing. All were retested at the end of their sixth session. No substantive changes in hearing were observed upon completion of the judgment tests. Twenty-two of the thirty test participants who judged the relative annoyance of the test signals were women ranging in age from 18 to 54, while eight were men ranging in age from 18 to 45. The average age of the female participants was 31, while the average age of the male participants was 27. The average test subject age was 30. Twenty-four of the test participants completed all of the six planned sessions; the remaining six completed five sessions each.

3.5 SOLICITATION OF ANNOYANCE JUDGMENTS

A paired comparison procedure was adopted to permit direct and immediate judgments of the relative annoyance of test signals. Subjects seated approximately one meter in front of a loudspeaker in an anechoic chamber were instructed to judge whether the first or second signal presentation of each trial was the more annoying. Figure 2 shows the temporal sequence of intra trial intervals. The durations of the signal presentation intervals were determined by the durations of the signals themselves. The duration of the response interval was determined by the test participant's response latency.

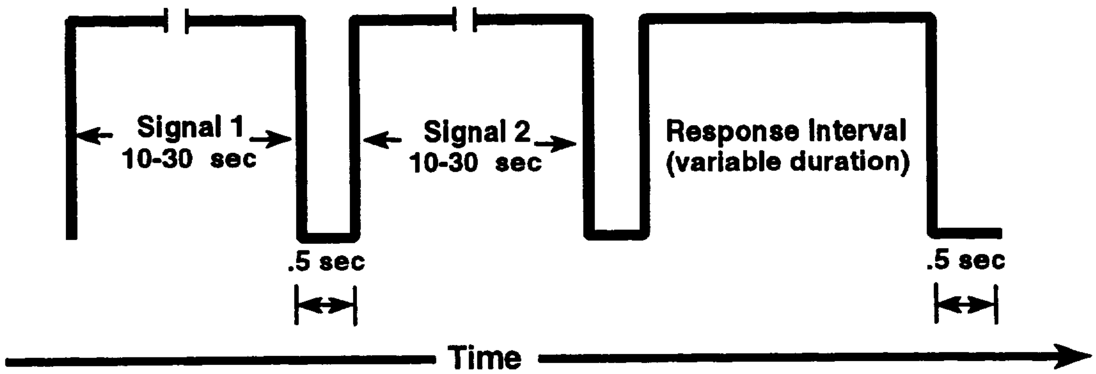
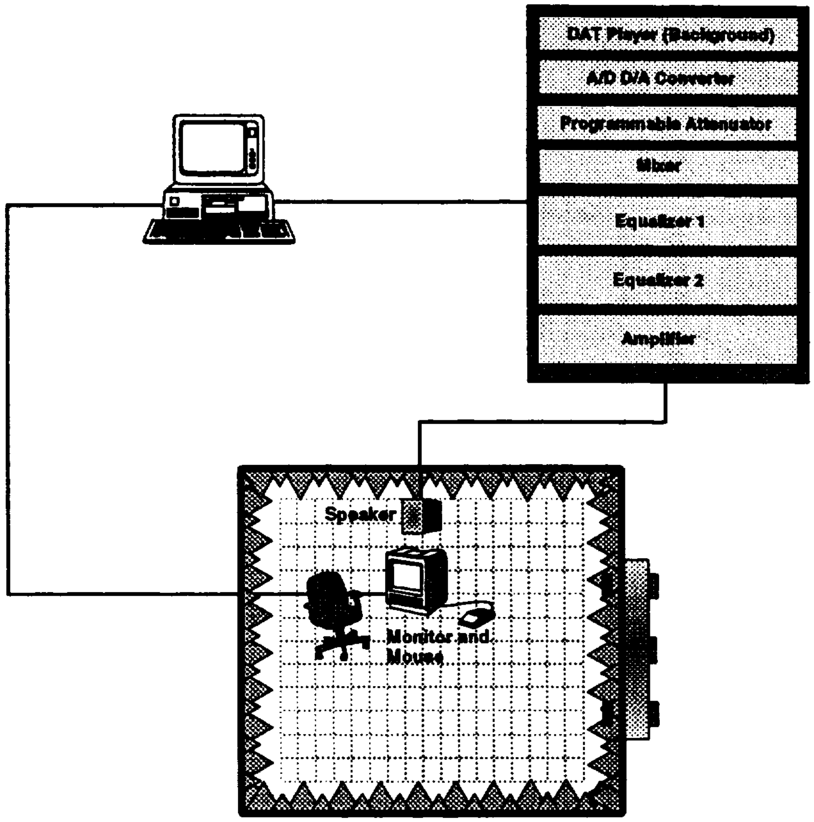


Figure 2 Temporal sequence of intra trial intervals.

Signal generation and presentation, as well as all other aspects of data collection, were under real time computer control. Figure 3 diagrams the signal generation and presentation hardware. A maximum likelihood estimation algorithm described by Green (1990, 1995) and by Zhou and Green (1995) adaptively controlled signal presentation levels in real time, on the basis of test participants' ongoing decisions. The underlying psychometric function was assumed to be a cumulative Gaussian with a standard deviation of 10 dB. The value of the estimated point on the psychometric function was 50%: the point of subjective equality of annoyance, at which individual test subjects rated the comparison (variable level signal) more annoying 50% of the time and the standard (fixed level) signal more annoying 50% of the time.

This point was approached by a binary search algorithm. The maximum step size permitted between trials was 30 dB, while the minimum step size was 0.5 dB. The maximum permissible signal presentation level was approximately 100 dB. Twelve trials were administered for each determination of the relative annoyance of signal pairs, sufficient to yield a standard deviation of the threshold estimate of approximately 4 dB. Practice sequences of eight trials, in which test participants compared the annoyance of signals against themselves, were conducted prior to the start of data collection.



Anechoic Chamber

Figure 3 Diagram of adaptive signal generation and response recording system.

The annoyance of all 34 standard (fixed level) test signals was judged relative to that of two comparison (variable level) test signals. One of the comparison (variable level) signals was a B-727 takeoff, while the other was a short duration (10 sec) simulation of an aircraft takeoff. The order of presentation of the fixed and variable signals was random on a trialwise basis. The order of presentation of signal pairs was independently randomized and fully interleaved. Testing was conducted in separate sessions lasting approximately 25 minutes each.[1] Test participants were required to leave the anechoic chamber between testing sessions. Their instructions may be found in Appendix A.

A highly compressed, long term recording of general urban noise mixed with shaped Gaussian noise was reproduced at all times that test participants were present in the anechoic chamber. The A-level of the background noise at the test participant's head position was approximately 47 dB. Figure 4 shows its spectral shape

[1] Since test participants were not forced to respond within a fixed duration response interval, the pace of data collection varied slightly from session to session.

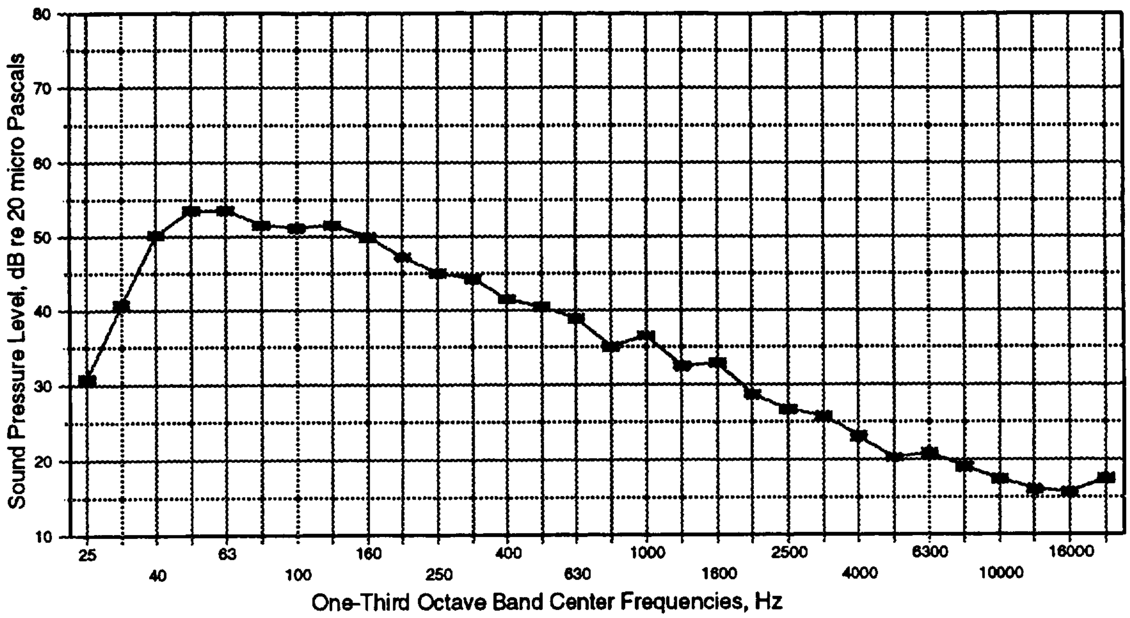


Figure 4 Simulated urban background noise heard at all times that test participants were present in the anechoic chamber.

4 RESULTS

This section describes the findings of the paired comparison judgments against the two variable level signals.

4.1 DATA COLLECTION AND PROCESSING

4.1.1 Data Screening

The 23,616 paired comparison judgments collected during testing permitted 1,968 potential determinations of points of subjective equality of annoyance. The basic datum analyzed was the noise level of a variable signal when judged equal in annoyance to each fixed test signal. Sequences of fewer than 12 signal presentations occurred in several instances, either because of participants' inattention or because the limits of the signal presentation levels were exceeded. No data from trial sequences of fewer than 12 signal pair presentations were analyzed. Five judgments that differed from the mean by more than 30 dB were also excluded from the data analysis as outliers. The total number of judgments of points of subjective equality of annoyance available for analysis after all data screening was 1,945.

4.2 FORM OF GRAPHIC DATA PRESENTATION

Points of subjective equality of annoyance averaged over all test participants are plotted throughout this report as differences between the level of the variable signal and that of the fixed signal to which it was judged equally annoying. The magnitudes of these differences vary for the 30 noise metrics calculated for each signal. A noise metric that was a completely accurate predictor of annoyance would show a level difference of 0 dB between the variable and fixed signals at the point of subjective equality of annoyance.

Figure 7 shows the differences averaged over all test participants for determinations of the points of subjective equality between all fixed test signals and both variable signals (B-727 takeoff and the simulated aircraft takeoff). The connected points in the figure display the standard deviation of all of the data. Figures 8 and 5 are comparable graphs showing similar trends for the two comparison signals separately. The metrics are ordered on the abscissa in groups of three. Within groups, the leftmost value plotted is the average metric, the middle value is the maximum metric, and the rightmost is the time integrated metric. Groups of metrics are positioned along the abscissa in rough order of accuracy of prediction, with the least accurate metrics toward the left of the figure and the most accurate metrics toward the right.

Figure 8 shows points of subjective equality of annoyance of test signals judged against themselves during the initial practice sessions. Figure 6 arbitrarily displays the results in terms of differences in maximum A-weighted level (MXMA); since the two signals compared are identical, any other metric would show the same pattern. The average differences of less than 1 dB for 30 test participants demonstrate the utility of the maximum likelihood estimation algorithm for determining points of subjective equality of annoyance in paired comparison testing. The repeatability of annoyance judgments by this method was also confirmed empirically. One of the test signals (SIMT) was compared to a fixed signal (M80T) both in practice sessions (8 presentations) and in the data collection trial sequences (12 presentations). Differences in points of subjective equality of annoyance for repeated determinations with the same signal pairs were less than 1 dB when averaged across all participants.

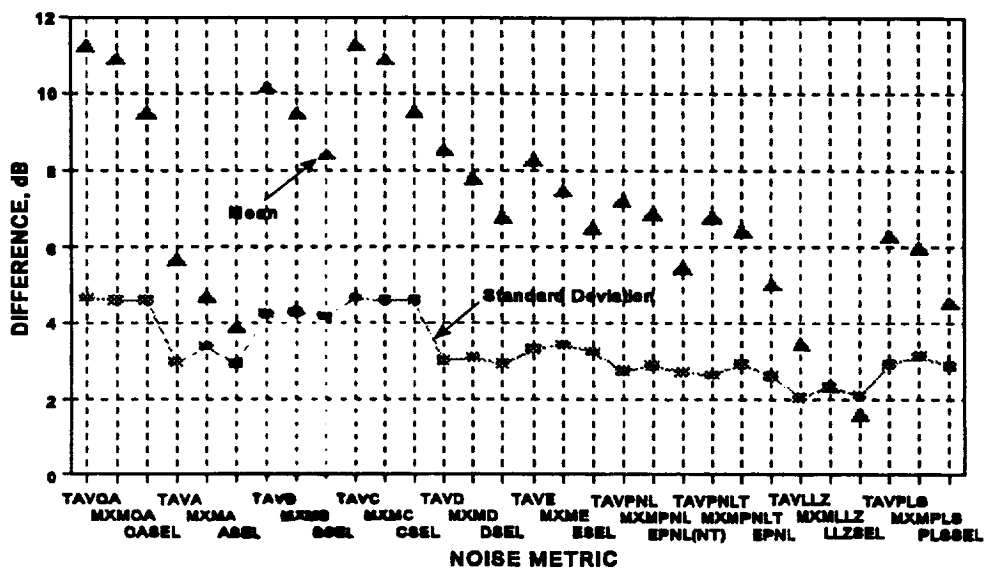


Figure 5 Average difference in noise metric of all test signals when judged equally annoying to SIMT (SIMT - test signal)

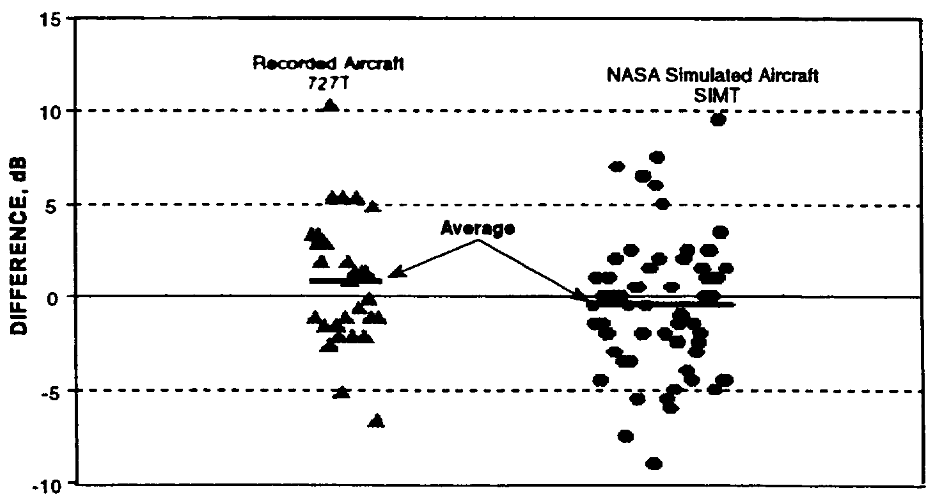


Figure 6 Differences in A-level of the same test signal when judged equally annoying to itself.

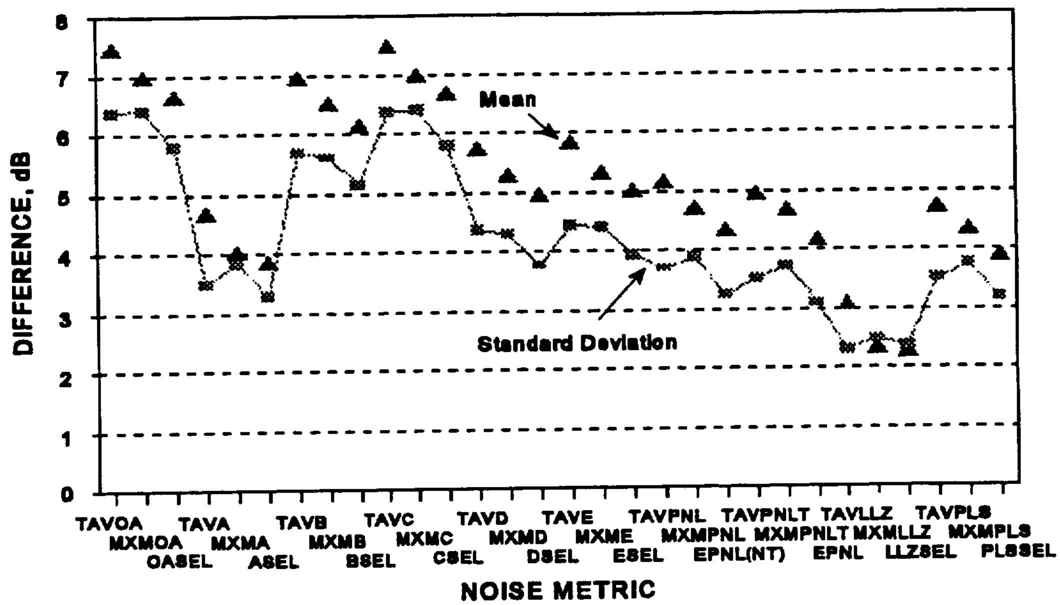


Figure 7 Average difference in noise metric of all test signals when judged equally annoying to both 727T and SIMT ((727T - test signal) and (SIMT - test signal)).

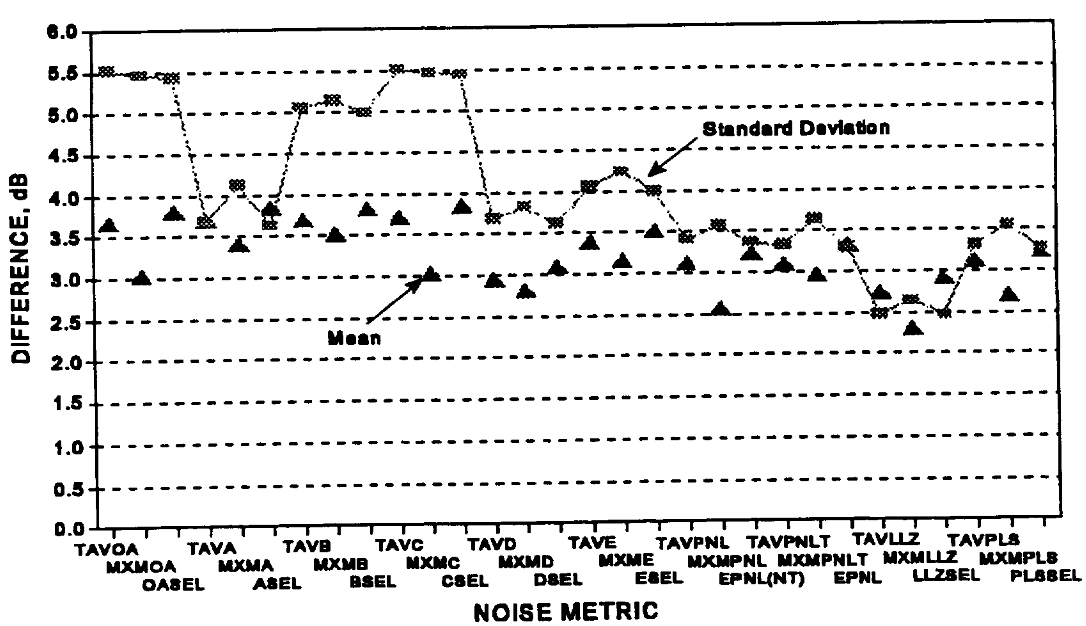


Figure 8 Average difference in noise metric of all test signals when judged equally annoying to 727T (727T - test signal).

4.3 DETAILS OF PAIRED COMPARISON JUDGMENTS

To avoid a confusing proliferation of figures, results are plotted in the remainder of this report in terms of three basic metrics: Maximum A-level (MXMA), Effective Perceived Noise Level (EPNL), and a sound exposure type of measure based on Zwicker's loudness level (LLZSEL). The first metric was selected as a simple and widely understood one; the second because it is the metric of choice in aircraft noise certification; and the third because it exhibited the smallest differences between standard and comparison signals at points of subjective equality of annoyance. Appendix B contains complete tables of these points of subjective equality of annoyance tables averaged over all test participants for the convenience of readers wishing to re-plot or reinterpret these findings in other units.

4.3.1 Comparisons Against the B-727 Takeoff

Points of subjective equality of annoyance for each of the thirty individual test participants are plotted in Figure 9 for comparisons made against the recorded B-727 takeoff to provide a general indication of the range of judgments. (Note that many of the individual data points are plotted over one another.) The results are plotted in terms of MXMA for each of the test signals identified in Tables 1 and 3. Figure 9 also contains the comparison of this signal against itself (at Signal 4), with somewhat smaller dispersion of judgments than for other signals.

Figures 10 through 18 show points of subjective equality of annoyance averaged over all test participants results for the 34 test signals, separated by operation type and noise source category as shown in Table 2. Three graphs are presented for each noise metric. Figures 10 through 12 show the averaged results in terms of MXMA, Figures 13 through 15 show the averaged results in terms of EPNL, and Figures 16 through 18 show the averaged results in terms of LLZSEL. The first of the

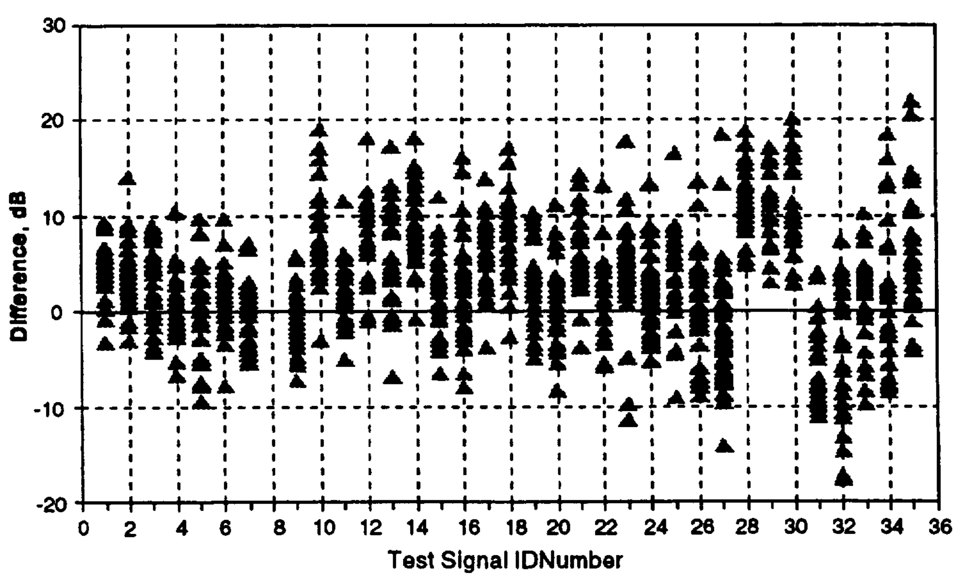


Figure 9 Difference in maximum A-level of the test signal when judged equally annoying to 727T (727 takeoff - test signal).

graphs in each set presents findings for comparisons of takeoffs, the second for comparisons of landings, and the third for comparisons of flyovers or passbys. Test signals corresponding to Stage I aircraft are presented first, followed by those for Stage II and III aircraft. Comparisons involving simulated future aircraft for which only simulations of takeoffs and landings were available are presented last. The results are ordered by decreasing EPNL differences within each aircraft stage, regardless of the metric under consideration.

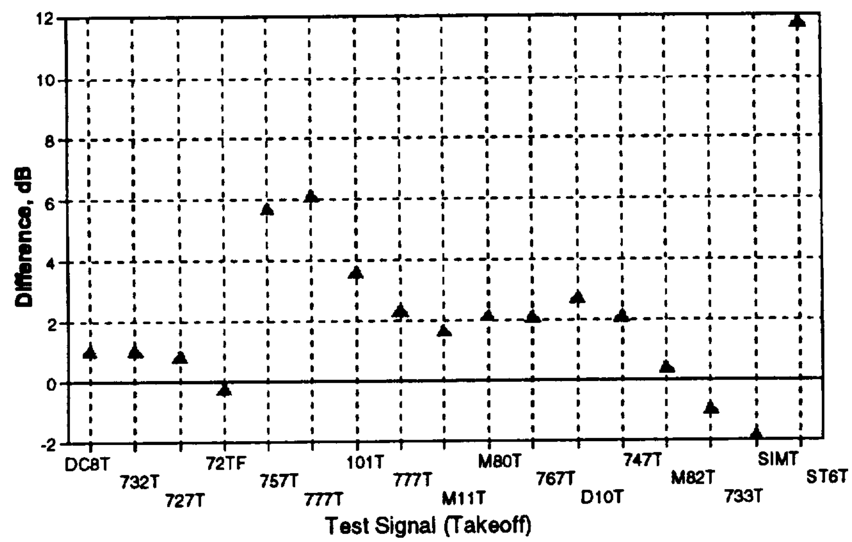


Figure 10 Results for takeoffs in terms of differences in MXMA of the pairs of signals when 727T is judged equally annoying to the test signal (727 takeoff - test signal).

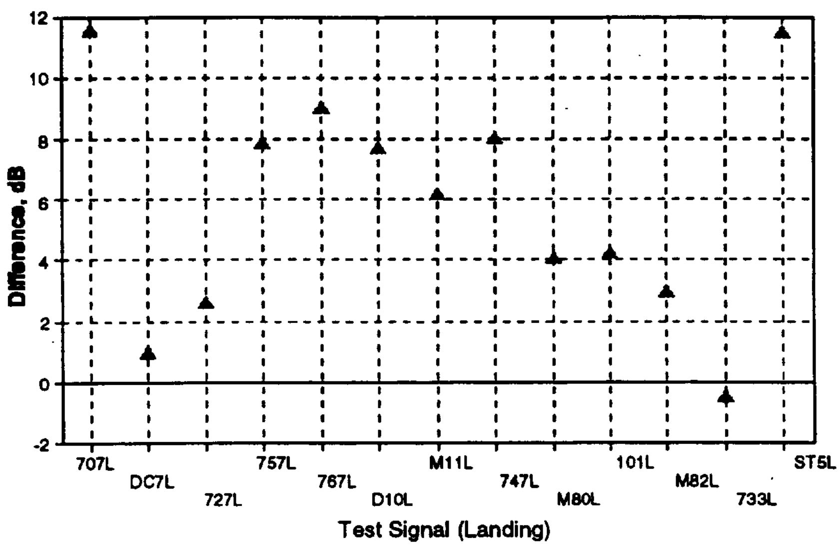


Figure 11 Results for landings in terms of differences in MXMA of the pairs of signals when 727T is judged equally annoying to the test signal (727 takeoff - test signal).

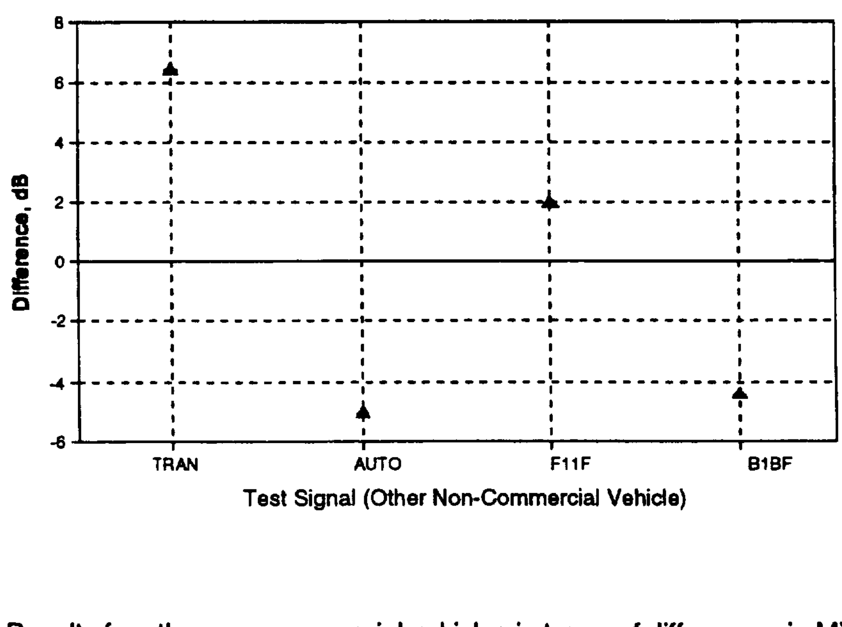


Figure 12 Results for other non-commercial vehicles in terms of differences in MXMA of the pairs of signals when 727T is judged equally annoying to the test signal (727 takeoff - test signal).

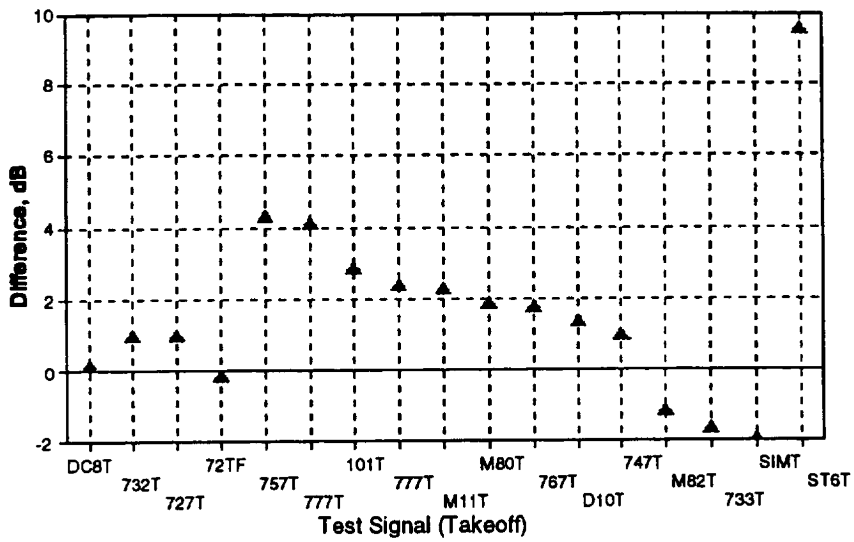


Figure 13 Results for takeoffs in terms of differences in EPNL of the pairs of signals when 727T is judged equally annoying to the test signal (727 takeoff - test signal).

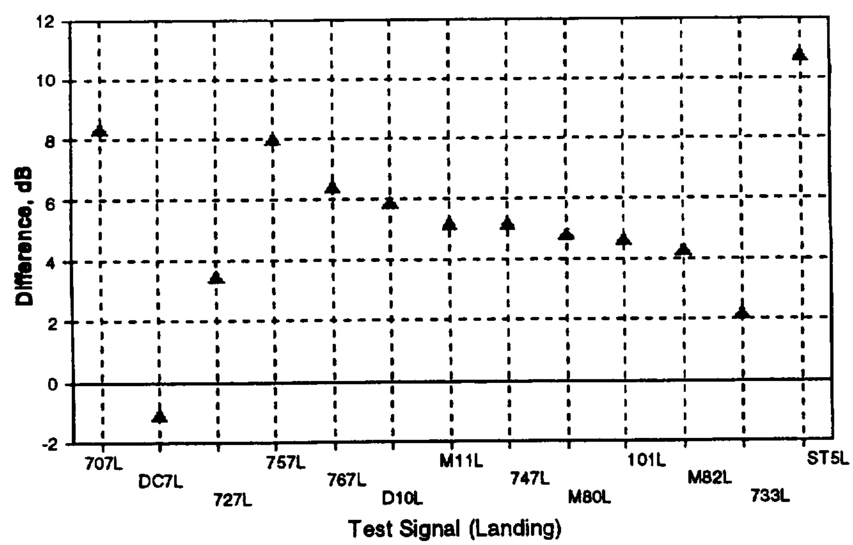


Figure 14 Results for landings in terms of differences in EPNL of the pairs of signals when 727T is judged equally annoying to the test signal (727 takeoff - test signal).

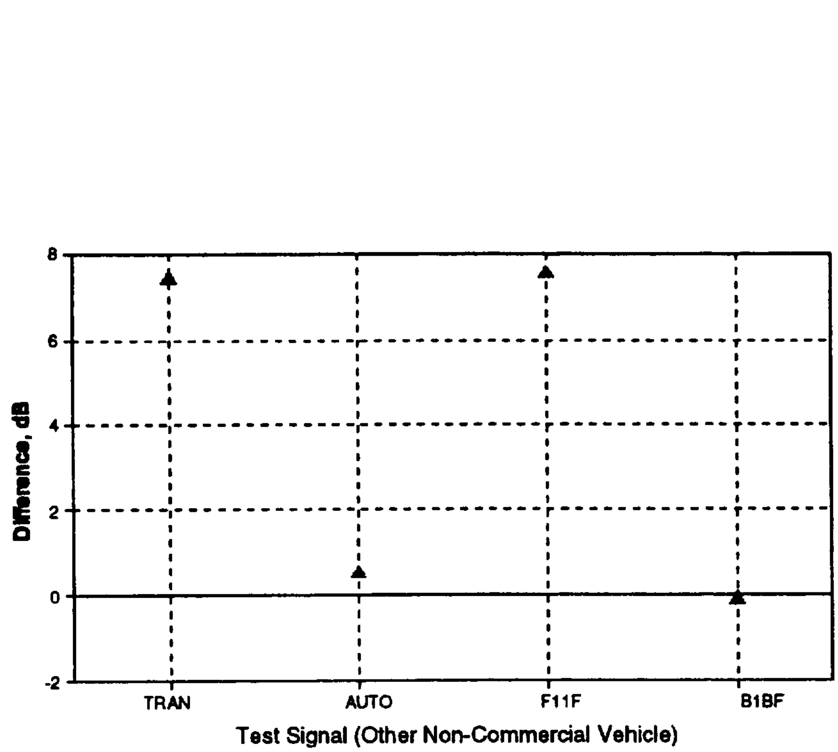


Figure 15 Results for other non-commercial vehicles in terms of differences in EPNL of the pairs of signals when 727T is judged equally annoying to the test signal (727 takeoff - test signal).

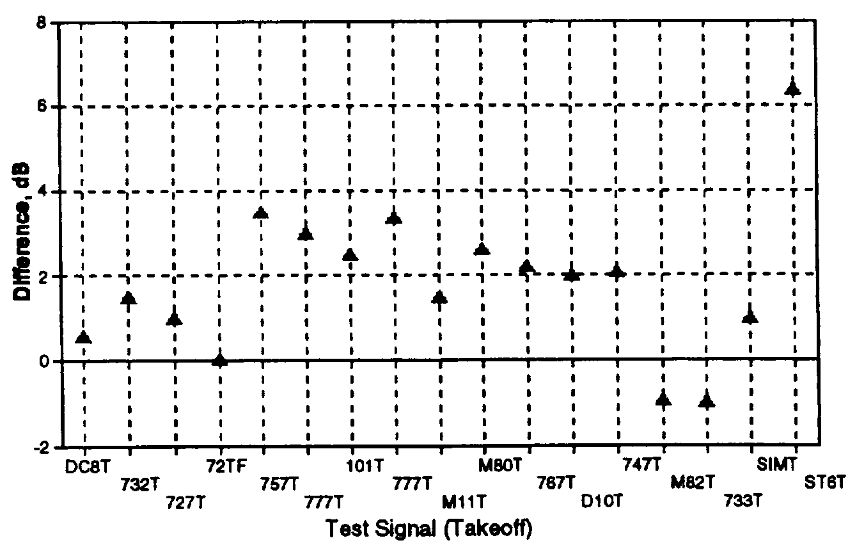


Figure 16 Results for takeoffs in terms of differences in LLZSEL of the pairs of signals when 727T is judged equally annoying to the test signal (727 takeoff - test signal).

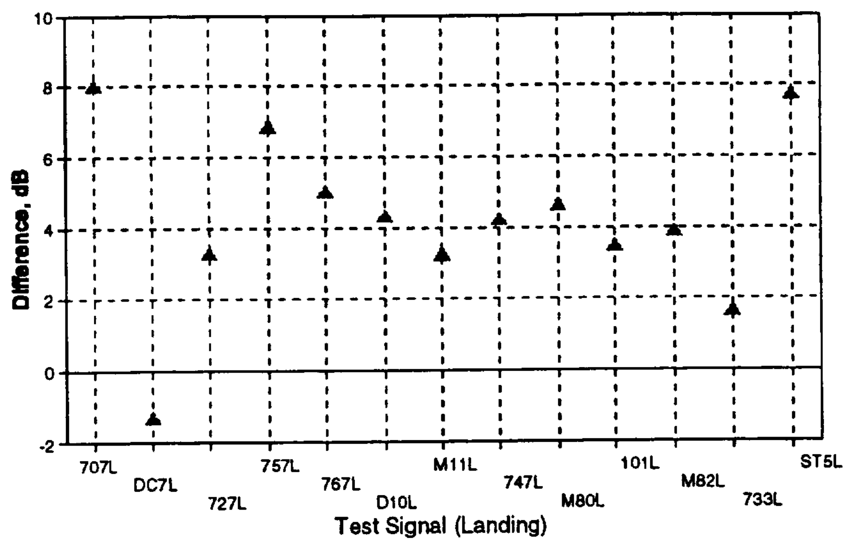


Figure 17 Results for landings in terms of differences in LLZSEL of the pairs of signals when 727T is judged equally annoying to the test signal (727 takeoff - test signal).

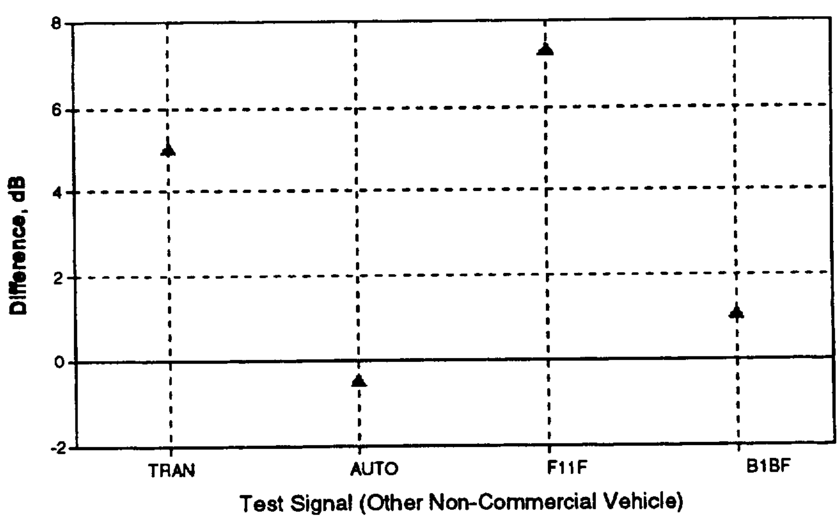


Figure 18 Results for other non-commercial vehicles in terms of differences in LLZSEL of the pairs of signals when 727T is judged equally annoying to the test signal (727 takeoff - test signal).

4.3.2 Comparisons Against the Simulated Aircraft Takeoff Signal

Figures 19 through 28 show averaged judgments of points of subjective equality of annoyance for comparisons against the simulated aircraft takeoff. Figure 19 summarizes findings in terms of MXMA for cases in which the takeoff was compared to the various fixed signals. Signal identification numbers for the fixed signals correspond to those listed in Tables 2 and 3. Figures 20 through 22 show the averaged results for each of the test signals in terms of MXMA. Figures 23 through 25 and Figures 26 through 28 show the averaged results for EPNL and LLZSEL, respectively.

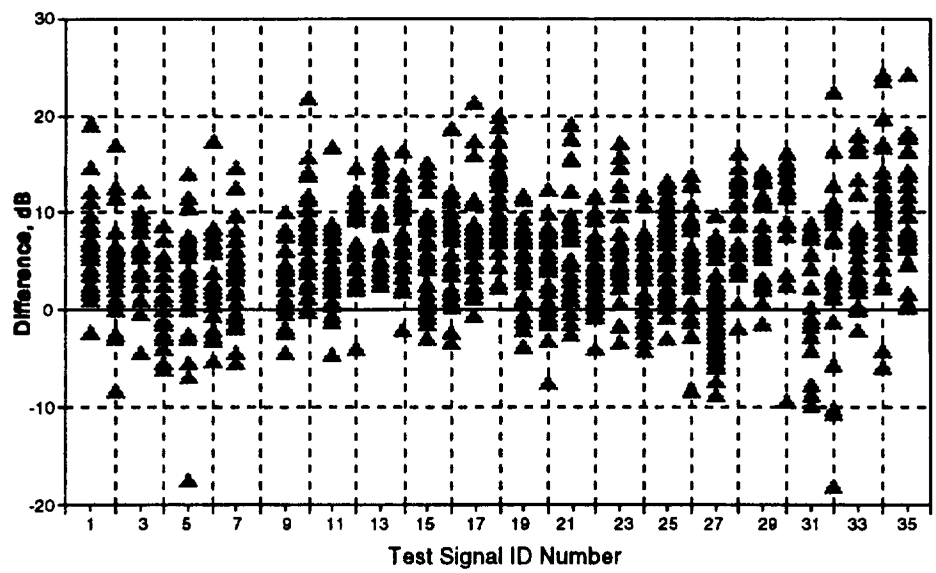


Figure 19 Difference in maximum A-level of the test signal when judged equally annoying to SIMT (SIM takeoff - test signal).

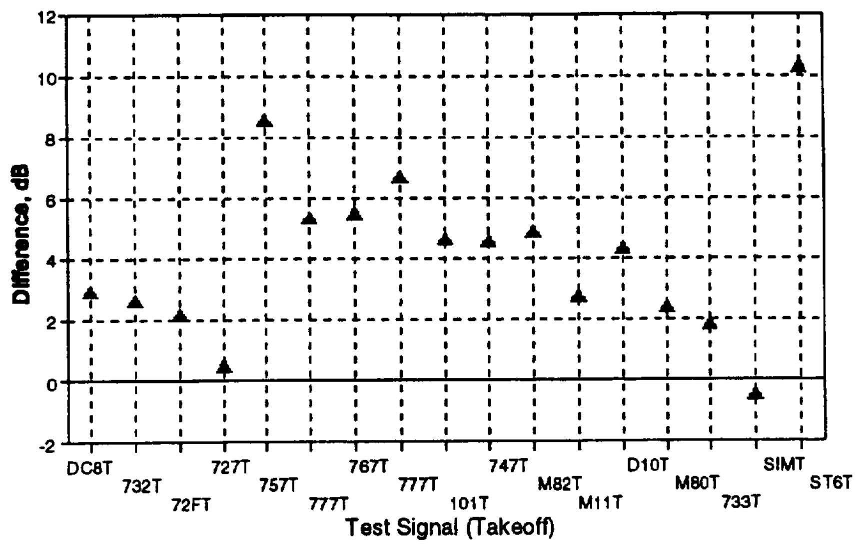


Figure 20 Results for takeoffs in terms of differences in MXMA of the pairs of signals when SIMT is judged equally annoying to the test signal (SIM takeoff - test signal).

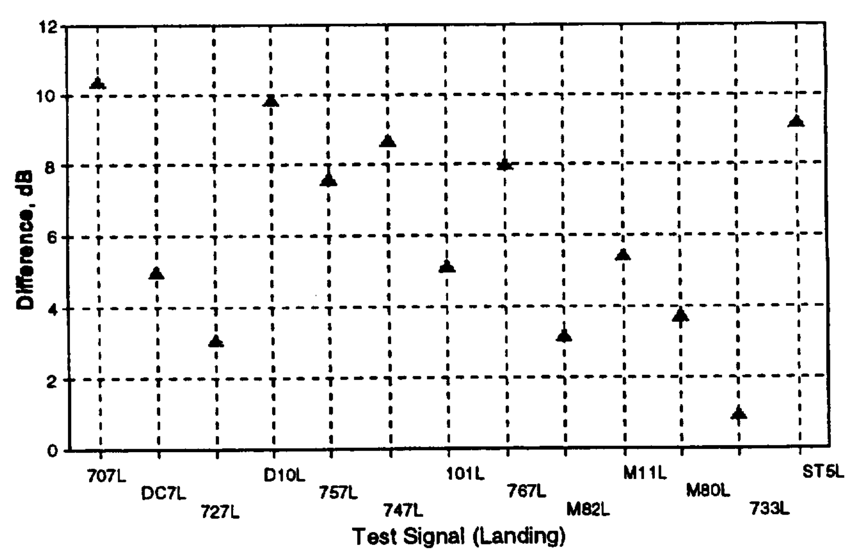


Figure 21 Results for landings in terms of differences in MXMA of the pairs of signals when SIMT is judged equally annoying to the test signal (SIM takeoff - test signal).

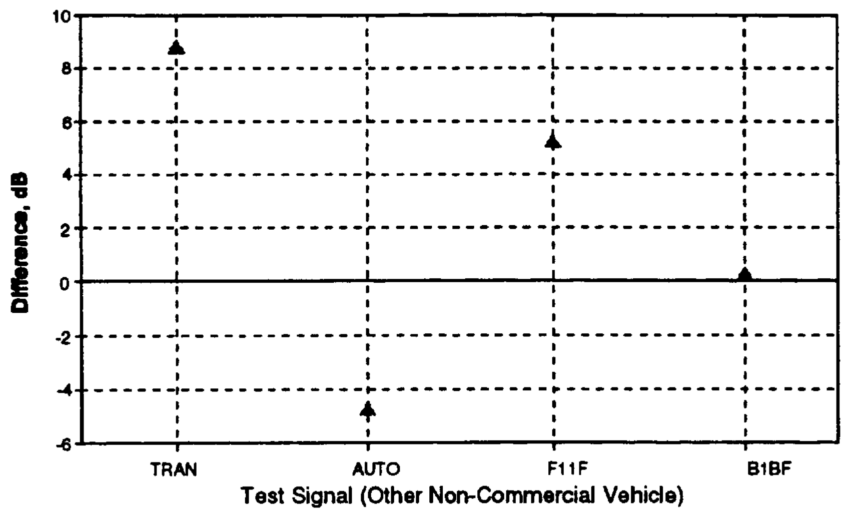


Figure 22 Results for other non-commercial vehicles in terms of differences in MXMA of the pairs of signals when SIMT is judged equally annoying to the test signal (SIM takeoff - test signal).

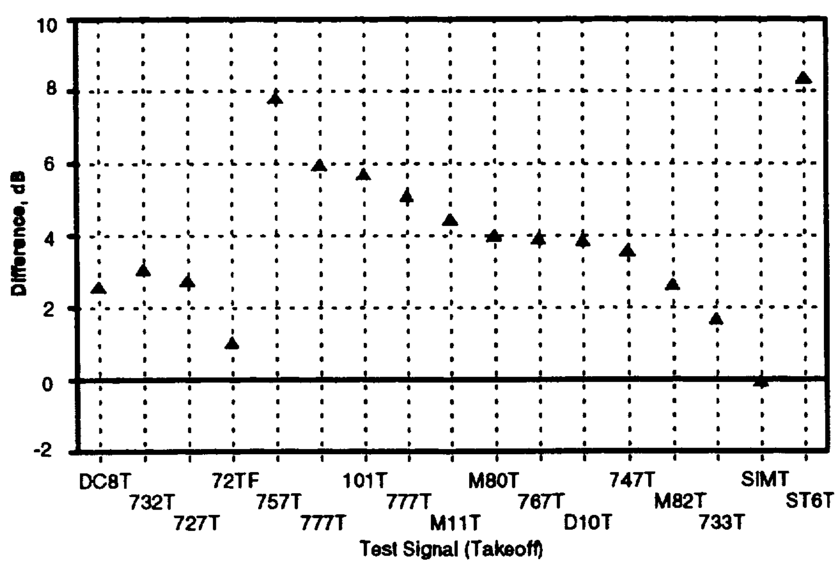


Figure 23 Results for takeoffs in terms of differences in EPNL of the pairs of signals when SIMT is judged equally annoying to the test signal (SIM takeoff - test signal).

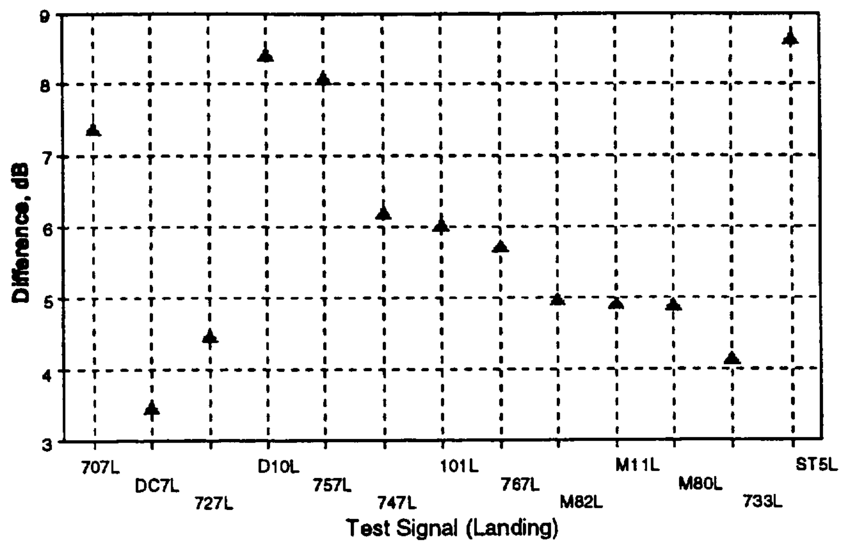


Figure 24 Results for landings in terms of differences in EPNL of the pairs of signals when SIMT is judged equally annoying to the test signal (SIM takeoff - test signal).

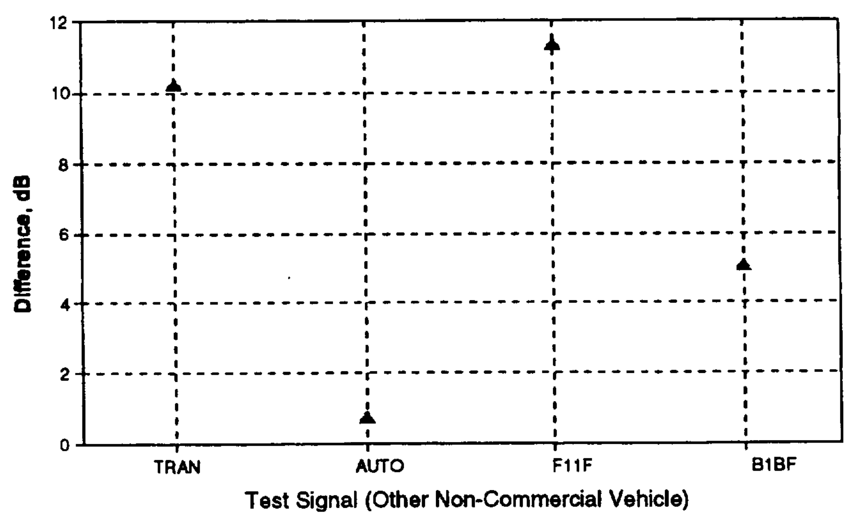


Figure 25 Results for other non-commercial vehicles in terms of differences in EPNL of the pairs of signals when SIMT is judged equally annoying to the test signal (SIM takeoff - test signal).

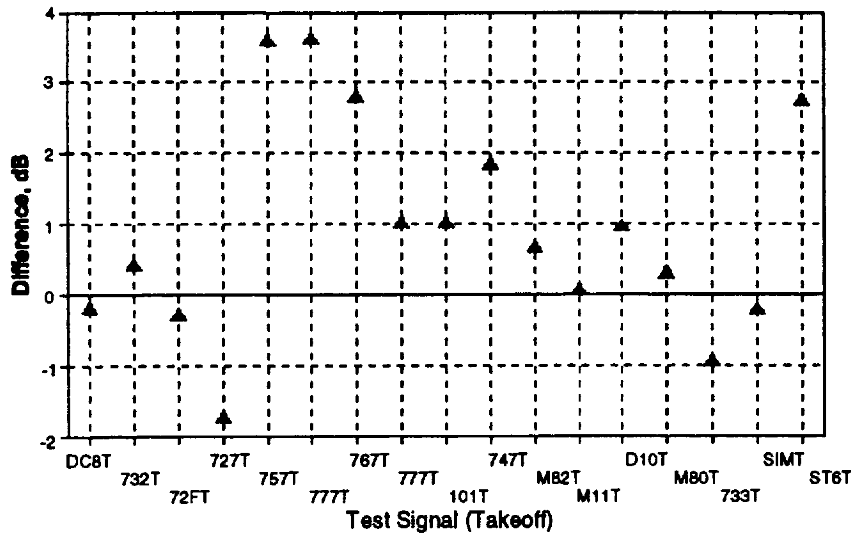


Figure 26 Results for takeoffs in terms of differences in LLZSEL of the pairs of signals when SIMT is judged equally annoying to the test signal (SIM takeoff - test signal).

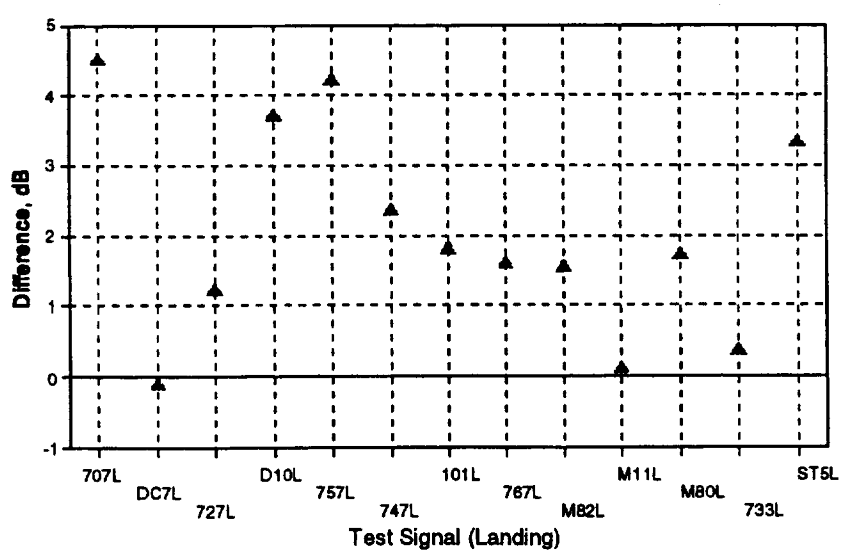


Figure 27 Results for landings in terms of differences in LLZSEL of the pairs of signals when SIMT is judged equally annoying to the test signal (SIM takeoff - test signal).

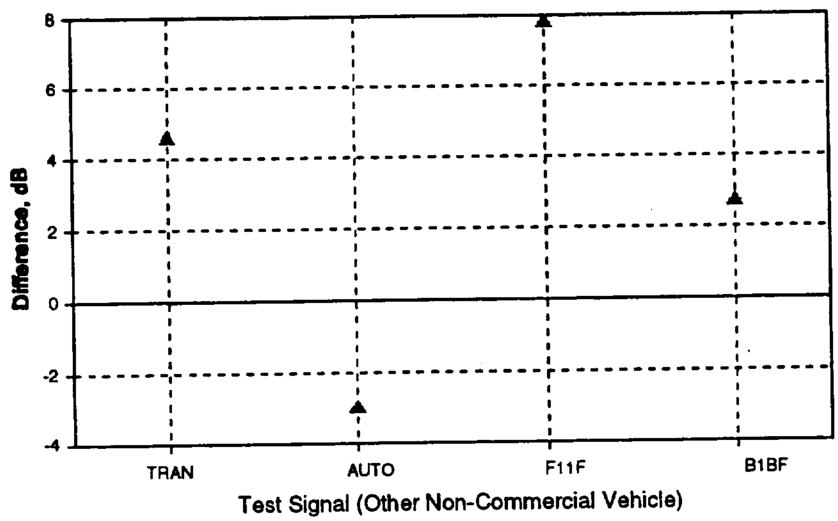


Figure 28 Results for other non-commercial vehicles in terms of differences in LLZSEL of the pairs of signals when SIMT is judged equally annoying to the test signal (SIM takeoff - test signal).

5 DISCUSSION

5.1 PERFORMANCE OF CLASSES OF NOISE METRICS AS PREDICTORS OF ANNOYANCE JUDGMENTS

In general, noise metrics that accord relatively little emphasis to low frequency energy behaved comparably as predictors of the judged annoyance of the aircraft noise test signals. As shown in Figures 4 through 6, metrics which accorded relatively greater emphasis to low frequency energy (B, C, and Flat or Overall) were less effective as predictors of annoyance judgments. These figures also show that metrics based on Zwicker's Loudness Level predicted annoyance judgments with smaller offsets and standard deviations than less complex metrics. Metrics sensitive to signal duration afforded slightly improved performance as predictors of annoyance, even though the range in duration of test signals was small (10-20 seconds).

Although the range of 2 to 4.5 dB in standard deviations across test signals was as expected for the "better metrics" shown in Figures 5 through 7, the mean differences of 2 to 8 dB between signals judged equally annoying was unanticipated. It is apparent for two reasons that this offset is not an artifact of the estimation algorithm itself: (1) test participants were able to come within 1 dB of matching the annoyance of test signals to themselves; and (2) the offset from 0 dB was notably smaller for an SEL-like variant of Zwicker's Loudness Level metric than for the remainder of the metrics. The superiority of the Zwicker level metrics, although unexpected, does not appear to be artifactual.

5.2 DIFFERENCES IN ANNOYANCE AMONG SETS OF TEST SIGNALS

Indications of systematic under or over-prediction of annoyance among sets of similar types of signals are noteworthy. For example, a comparison of the findings for the three noise metrics shown in Figures 10 through 18 and Figures 20 through 28 suggest that annoyance of takeoff noise is more accurately predicted by the three metrics than the annoyance of landing noise. This effect is particularly evident in comparisons against the recorded B-727 takeoff.

The test signals that simulated future aircraft takeoffs and landings produced results quite different from most of the other test signals. EPNL differences of 8-11 dB were observed in these comparisons, suggesting that EPNL considerably underestimates the annoyance of such artificial signals. Similar underestimates are noted for the train and for the F111. EPNL also underestimated the annoyance of a 707 landing by 8 dB. Underestimates of the annoyance of the same test signal were also noted for other noise metrics.

5.3 IMPLICATIONS OF FINDINGS

The present findings suggest that EPNL may not be the single most effective predictor of the annoyance of aircraft overflights. A duration-adjusted variant of Zwicker's loudness level offers some small improvements in accuracy and precision over EPNL. Averaged over all comparisons, the difference between fixed and variable test signals is 4.2 dB for EPNL but only 2.3 dB for LLZSEL. Further, the standard deviation for EPNL is 3.1 dB, but only 2.4 dB for LLZSEL. Stated another way, EPNL underestimates the annoyance of the test signals (most of which were produced by Stage III aircraft) by 4.2 dB, while LLZSEL underestimates the annoyance of these aircraft by only 2.3 dB.

Other findings, such as the apparent underestimation of the annoyance of landing with respect to takeoff noise, and the underestimation of the annoyance of noise from simulated future aircraft takeoffs and landings, merit further investigation, since the metric used to certify noise from aircraft overflights should accurately predict the annoyance of both takeoff and landing noise, regardless of engine type. It is possible that the observed mis-estimation of annoyance may be related to the reproduction of flyover noises recorded outdoors as they would be heard indoors.

6 CONCLUSIONS

The following observations may be made about the current data set of subjective judgments of the annoyance of aircraft overflight noise:

1) Unweighted (Flat and C-weighted) and B-weighted metrics afford the least accurate and precise estimates of the annoyance of overflights.

2) Most of the simple frequency weighted metrics are of comparable accuracy as predictors of the annoyance of overflights.

3) Time-integrated metrics provided slightly more accurate and precise estimates of the annoyance of aircraft overflights than maximum level measures, even though differences in test signal durations were minor.

4) A time-integrated variant of Zwicker's Loudness Level metric provided the most accurate and precise prediction of aircraft overflight annoyance.

5) The results of comparisons of test signals against a B-727 takeoff comparison are comparable to those observed in comparisons against a simulated aircraft takeoff.

6) The annoyance of simulations of takeoff and landing noise of future aircraft were most greatly underpredicted by all of the metrics under evaluation.

7 ACKNOWLEDGMENTS

The authors are grateful to the test participants for their diligence. Cooperation of airport officials with the field data collection at McCarran Airport in Las Vegas is much appreciated. David McCurdy and John Ollerhead generously contributed certain recordings and simulations for processing into test signals. David Barber and Shawntise Turner assisted with the field data collection. Elizabeth Fletcher was responsible for production of this document.

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9 GLOSSARY

Terms in this Glossary are defined as by *American National Standard S1.1-1994 Acoustical Terminology*.

sound pressure; effective sound pressure. Root-mean-square instantaneous sound pressure at a point, during a given time interval. Unit, pascal (Pa).

> NOTE - In the case of periodic sound pressures, the interval is an integral number of periods or an interval that is long compared to a period. In the case of non-periodic sound pressures, the interval should be long enough to make the measured sound pressure essentially independent of small changes in the duration of the interval.

sound exposure. Time integral of squared, instantaneous frequency-weighted sound pressure over a stated time interval or event. Unit: pascal-squared second; symbol, E.

> NOTES
>
> 1 If frequency weighting is not specified, A-frequency weighting is understood. If other than A- frequency weighting is used, such as C-frequency weighting, an appropriate subscript should be added to the symbol; i.e., E_C.
>
> 2 Duration of integration is implicitly included in the time integral and need not be reported explicitly. For the sound exposure measured over a specified time interval such as one hour, a 15-hour day, or a 9-hour night, the duration should be indicated by the abbreviation or letter symbol, for example one-hour sound exposure (1HSE or E_{1h}) for a particular hour; day sound exposure (DSE or E_d) from 0700 to 2200 hours; and night sound exposure (NSE or E_n) from 0000 to 0700 hours plus from 2200 to 2400 hours.
>
> 3 Day-night sound exposure (DNSE or E_{dn}) for a 24-hour day is the sum of the day sound exposure and ten times the night sound exposure.
>
> 4 Unless otherwise stated, the normal unit for sound exposure is the pascal-squared second.

perceived noise level. Frequency-weighted sound pressure level obtained by a stated procedure that combines the sound pressure levels in the 24 one-third octave bands with midband frequencies from 50 Hz to 10 kHz. Unit, decibel (dB); abbreviation, PNL; symbol, L_{PN}.

> NOTE – Procedures for computing perceived noise level are stated in Federal Aviation Regulation Part 36, *Noise Standards: Aircraft Type and Airworthiness Certification*, Appendix B, and in International Civil Aviation Organization Annex 16, Volume 1, *Aircraft Noise*, Third Edition, July 1993.

sound pressure level. (a) Ten times the logarithm to the base ten of the ratio of the time-mean-square pressure of a sound, in a stated frequency band, to the square of the reference sound pressure in gases of 20 μPa. Unit, decibel (dB); abbreviation, SPL; symbol, L_p.

sound level; weighted sound pressure level. Ten times the logarithm to the base ten of the ratio of A-weighted squared sound pressure to the squared reference sound pressure of 20 μPa, the squared sound pressure being obtained with fast (F) (125-ms) exponentially weighted time-averaging. Alternatively, slow (S) (1000-ms) exponentially weighted time-averaging may be specified; also C-frequency weighting. Unit, decibel (dB); symbol L_A, L_C.

> NOTES
>
> 1 In symbols, A-weighted sound level $L_{A\tau}(t)$ at running time t is:

$$L_{A\tau}(t) = 10 \lg\{[(1/\tau) \int_{-\infty}^{t} p_A^2(\xi) e^{-(t-\xi)/\tau} d\xi] / p_0^2\}$$

where τ is the exponential time constant in seconds, ξ is a dummy variable of integration, $p_A^2(\xi)$ is the squared, instantaneous, time-varying, A-weighted sound pressure in pascals, and p_0 is the reference sound pressure of 20 μPa. Division by time constant τ yields the running time average of the exponential-time-weighted, squared sound-pressure signal. Initiation of the running time average from some time in the past is indicated by $-\infty$ for the beginning of the integral.

2 ANSI S1.4-1983, *American National Standard Specification for Sound Level Meters*, gives standard frequency weightings A and C and standard exponential time weightings fast (F) and slow (S).

maximum sound level; maximum frequency-weighted sound pressure level. Greatest fast (125-ms) A-weighted sound level, within a stated time interval. Alternatively, slow (1000 ms) time-weighting and C frequency-weighting may be specified. Unit, decibel (dB); abbreviation, MXFA; symbol, L_{AFmx} (or C and S).

time-average sound level; time-interval equivalent continuous sound level; time-interval equivalent continuous A-weighted sound pressure level; equivalent continuous sound level. Ten times the logarithm to the base ten of the ratio of time-mean-square instantaneous A-weighted sound pressure, during a stated time interval T, to the square of the standard reference sound pressure. Unit, decibel (dB); respective abbreviations, TAV and TEQ; respective symbols, L_{AT} and L_{AeqT}.

NOTES

1 A frequency weighting other than the standard A-weighting may be employed if specified explicitly. The frequency weighting that is essentially constant between limits specified by a manufacturer is called flat.

2 In symbols, time-average (time-interval equivalent continuous) A-weighted sound level in decibels is:

$$L_{AT} = 10 \lg\{[(1/T) \int_{0}^{T} p_A^2(t) dt]/p_o^2\}$$

$$= L_{AeqT}$$

where p_A^2 is the squared instantaneous A-weighted sound pressure signal, a function of elapsed time t; in gases reference sound pressure p_o = 20 μPa; T is a stated time interval.

3 In principle, the sound pressure signal is not exponentially time-weighted, either before or after squaring.

sound exposure level. Ten times the logarithm to the base ten of the ratio of a given time integral of squared instantaneous A-weighted sound pressure, over a stated time interval or event, to the product of the squared reference sound pressure of 20 micropascals and reference duration of one second. The frequency weighting and reference sound exposure may be otherwise if stated explicitly. Unit, decibel (dB); abbreviation, SEL; symbol, L_{AE}.

NOTE - In symbols, (A-weighted) sound exposure level is:

$$L_{AE} = 10 \lg\{[\int_{0}^{T} p_A^2(t) dt]/p_o^2 t_o\}$$

$$= 10 \lg(E/E_o)$$

$= L_{AT} + 10 \lg(T/t_o)$

where p_A^2 is the squared instantaneous A- weighted sound pressure, a function of time t; for gases p_o = 20 μPa; t_o = 1 s; E is sound exposure; $E_o = p_o^2 t_o$ = (20 μPa)^{2}s is reference sound exposure.

C-weighted sound exposure level. Sound exposure level, as defined in Part 1, where C-weighted sound pressure is used instead of A-weighted sound pressure. Unit, decibel; abbreviation, CSEL, symbol, L_{CE}.

energy summation. Colloquial term loosely used to indicate addition of noncoherent sound signals by the sum of the squares of their sound pressures or sound exposures.

energy average. Colloquial term for time-mean-square average of a series of sound signals.

APPENDIX A INSTRUCTIONS AND CONSENT FORM FOR TEST PARTICIPANTS

1 Instructions to Test Participants 1001

Your basic job will be to listen carefully to pairs of sounds that you will hear while seated in a special sound room, and to decide right after hearing each pair of sounds whether the first or the second of the sounds was the more annoying to you. Each pair of sounds is a "trial." Several dozen trials will be heard in each "session." You will have a rest break between each session, during which you should leave the sound room for five minutes.

A computer will select the pairs of sounds that you will hear, and record your decisions about which of the pair was the more annoying. The computer needs information about who you are, when to start playing the sounds, and so forth. The rest of these instructions describe how you get started and how you work with the computer during the experiment.

1.1 Log In

When you arrive you need to sign in on the computer in the laboratory using a Subject ID number that will be given to you by the experimenter. Go to the keyboard in the back of the control room and type **Alt-D**.

[The Alt key is located next to the space bar along the bottom of the keyboard. You must hold down this key at the same time that you press the "D" key.]

Once you press Alt-D, the Data Collection menu will open. You will have two options, "Run" and "Practice." Press the "R" key to select the **Run** option. Then press the **Enter** key. The computer will now ask you for your ID number. Type in your ID number (for example, 1234) and then press **Enter**. Once you have done that, walk into the sound room where you will be seated while listening to the pairs of sounds.

1.2 Beginning the Experiment

Once you have moved into the room where the experiment will take place, sit down in the chair facing the speaker and computer screen. You will find a computer "mouse" on a pad on the armrest of the chair. You will use this mouse to tell the computer when to play sounds and which of a pair of sounds is the more annoying.

The screen will ask you "Are you ready to begin Experiment..." As soon as you are comfortably seated and ready to start, move the mouse arrow to the "Yes" box and click the left mouse button once. This will start the test session.

You will be asked to judge the annoyance of several different pairs of sounds during each test session. Your job will always be to listen carefully to each sound in each pair, and to judge the noisiness of the sounds as you would if you heard them in your home twenty to thirty times a day. After the second sound of each pair ends, you will then be asked which of the two was the more annoying. The presentation of each pair of signals will look like this on the screen:

1. The screen will say "Experiment in Progress" and "Listen now for sound [1]." The computer will play the first sound

2. Then the screen will say "Listen now for sound [2]" and the computer will play the second sound.

3. Once the second sound has finished playing the screen will say "Which sound was more annoying?" and you will see two blue rectangles on the screen: one that says "First" and another that says "Second." Use the mouse to position the arrow over the first or second rectangle to tell the computer which sound you felt was more annoying. Then press the left mouse button. You will hear the next pair of sounds shortly after you press the left mouse button.

Each test session will last approximately 25 minutes, after which you should stand up, leave the sound room, and take a five minute break. You will be expected to finish four such sessions each day that you take part in this study, for a total of 2 hours per day.

When a test session is over, the computer will present a small box that says "You have finished Experiment ..." and an OK button. Click the OK button using the left mouse button, as soon as you are ready to continue. If there are more sessions scheduled for the day, a window will appear asking if you are ready to begin. Don't press the "Yes" button until you come back from your break and are ready to continue. Press the "Yes" button to continue with the next session after you are sitting down and are comfortable again.

If you have completed your four sessions for the day, answer "No" to the "Are You Ready for Experiment..." question.

1.3 Additional Information

If you feel uncomfortable in the sound room at any time, you may simply stand up, open the door and leave the room.

If the computer screen asks you to get the experimenter at any time during the session, you should stand up, open the door, and find the experimenter.

CONSENT FORM FOR AIRCRAFT NOISE ANNOYANCE STUDY

BBN Systems and Technologies (BBN) is conducting a laboratory study of the annoyance of the noise of certain aircraft flyovers, and would like you to take part in this research project. This form explains what is expected of people who wish to take part in this study. Please sign this form at the bottom after you have read it if you would like to take part in this study.

I understand that I will be asked to listen attentively to pairs of aircraft overflights, each lasting as long as 30 seconds, and to indicate which of the pair of sounds is the more annoying. Since the aircraft overflights will be heard at levels typical of airport communities, some may be uncomfortably loud. My participation in this test will not, however, pose any meaningful risk of hearing damage.

I understand that I will be given an audiogram prior to the start of my participation in these listening tests, and upon completion of testing. No other audiometric or medical services will be provided in connection with this testing.

All listening will be done in an anechoic chamber. Each testing session will last approximately two hours, with five minute breaks (during which I will leave the anechoic chamber) provided every half hour. I will also be free to leave the anechoic chamber at any time that I wish. I further understand that I may change my mind about taking part in this study at any time. If I decide to stop taking part in the study, I will be paid for the amount of time that I did take part.

I will be expected to take part in several such listening sessions, and will be paid at a daily rate of $20.00 for each day of testing.

I certify that I am 18 years of age or older, that I have read the information on this page, and that I want to take part in this study of aircraft noise annoyance.

Signed ______________________ Print Name ______________________

Date ______________________ Phone No. ______________________

1001

APPENDIX B SPECTRA OF TEST SIGNALS AT MAXIMUM A-LEVEL

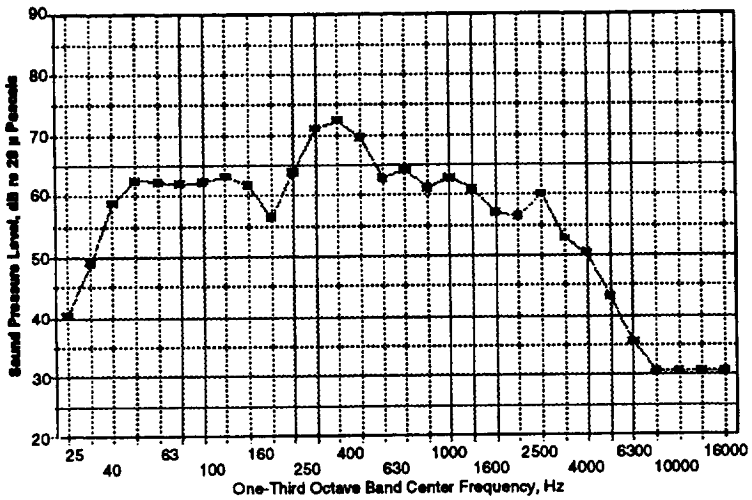

Figure 29 Test Signal 1—Lockheed L1011 Landing (101L).

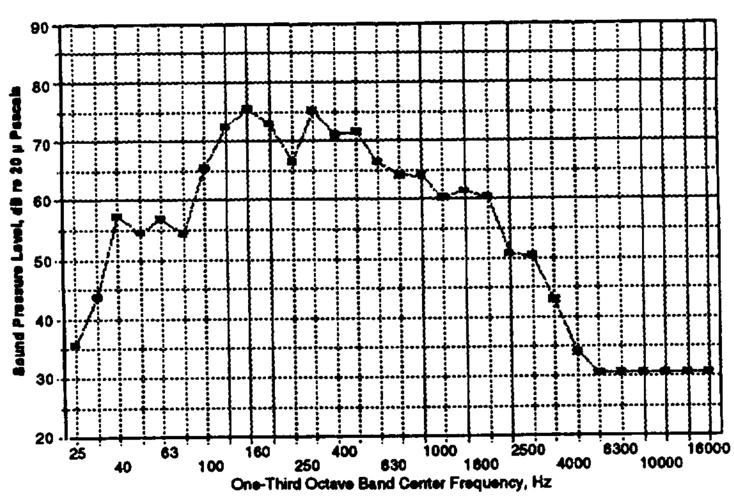

Figure 30 Test Signal 2—Lockheed L1011 Takeoff (101T).

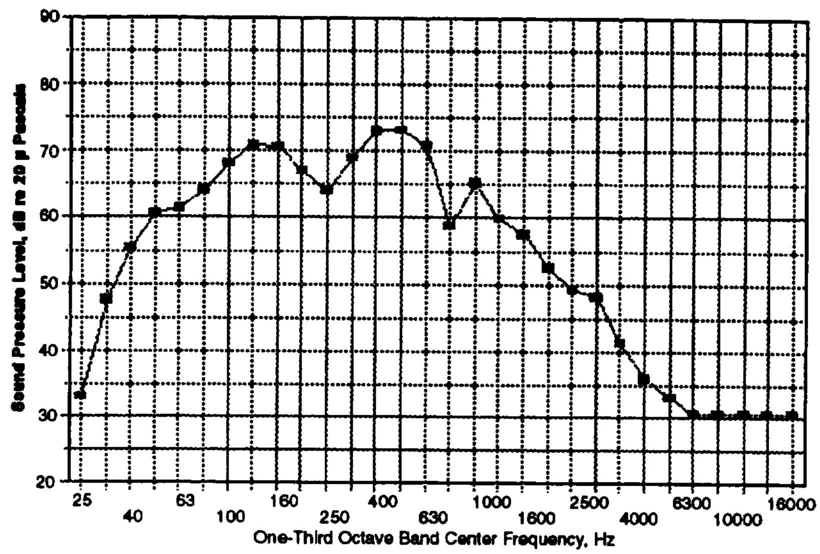

Figure 31 Test Signal 3—Boeing 727 Landing (727L).

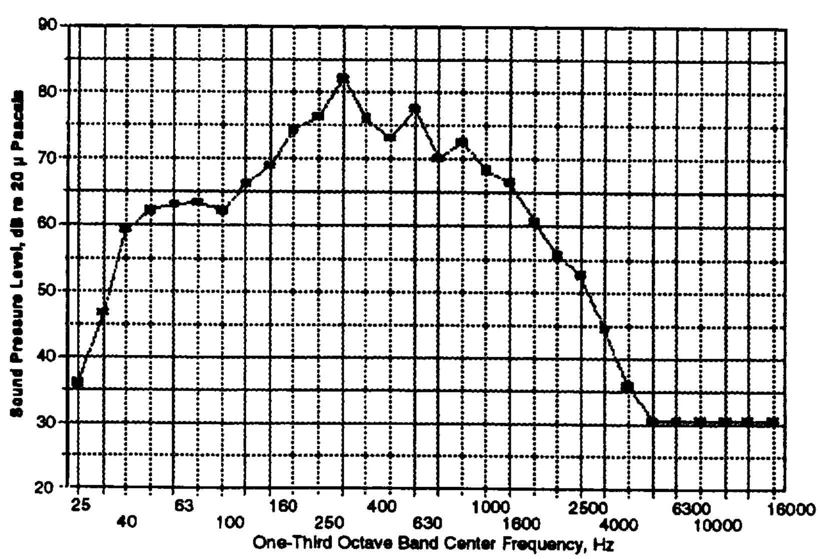

Figure 32 Test Signal 4—Boeing 727 Takeoff (727T).

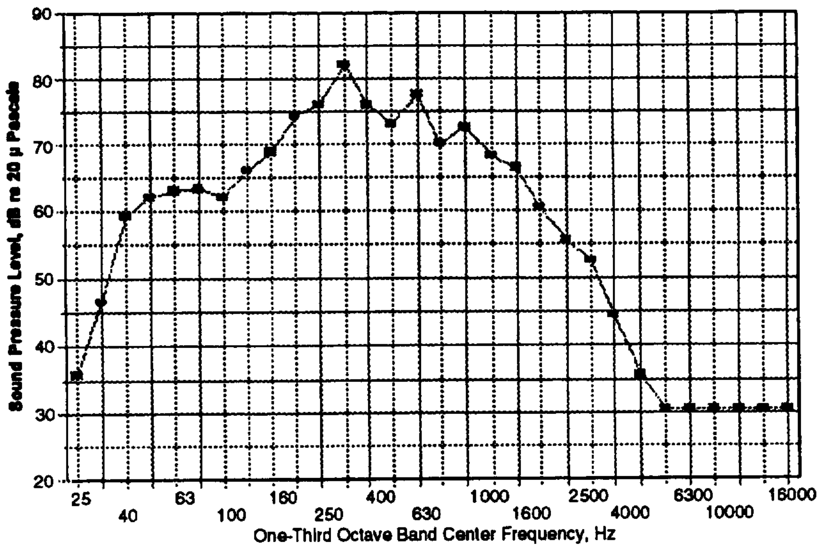

Figure 33 Test Signal 5—Boeing 727 Takeoff (long duration) (72TF).

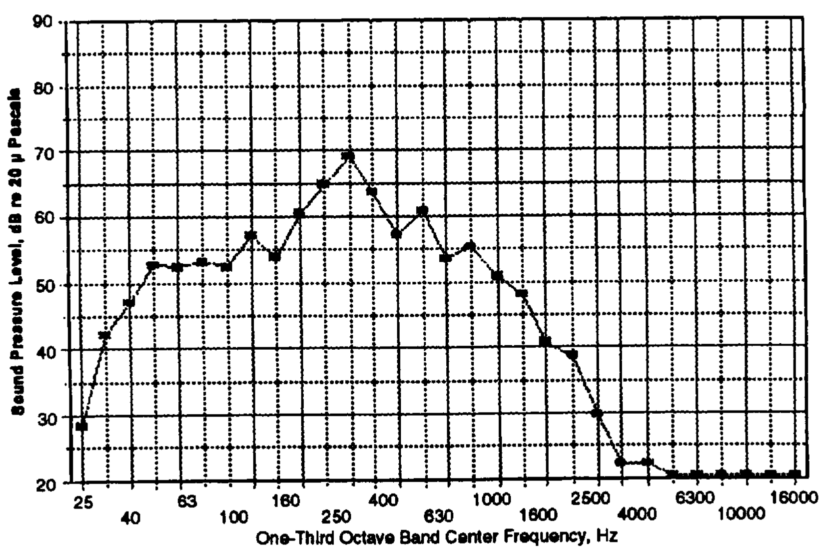

Figure 34 Test Signal 6—Boeing 737-200 Takeoff (732T).

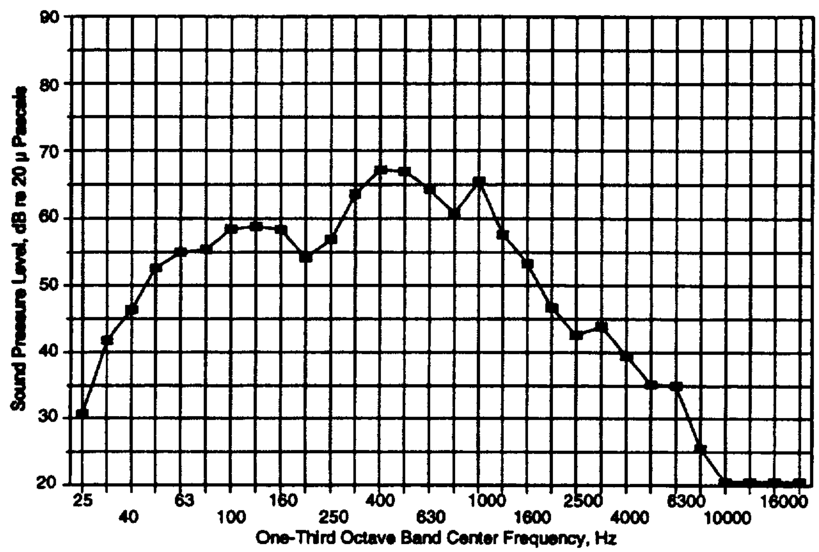

Figure 35 Test Signal 7—Boeing 737-300 Landing (733L).

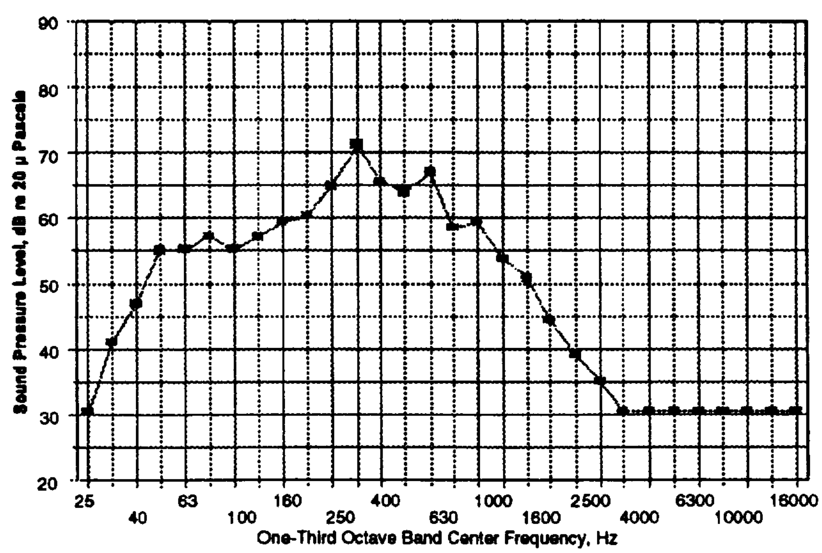

Figure 36 Test Signal 9—Boeing 737-300 Takeoff (733T).

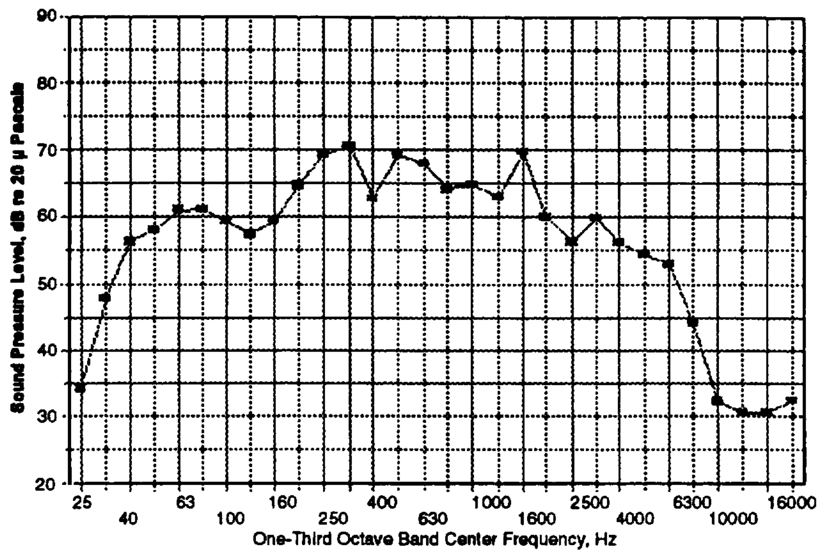

Figure 37 Test Signal 10—Boeing 747 Landing (747L).

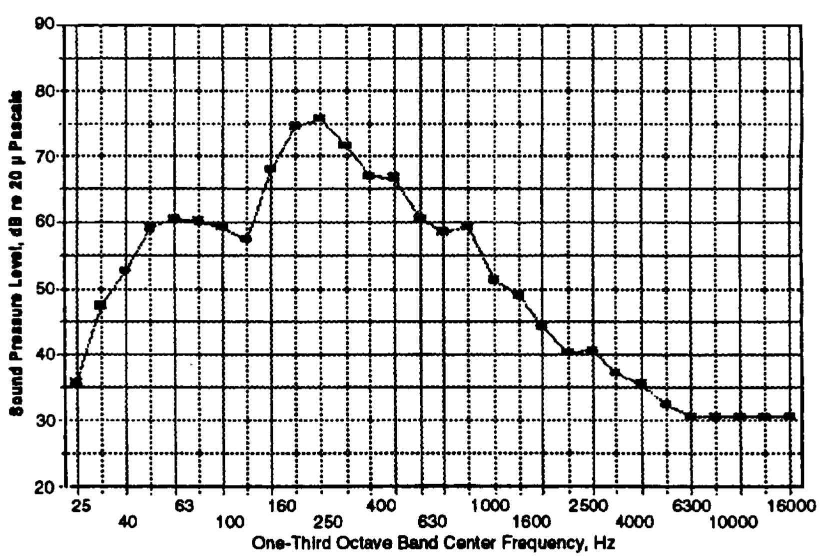

Figure 38 Test Signal 11—Boeing 747 Takeoff (747T).

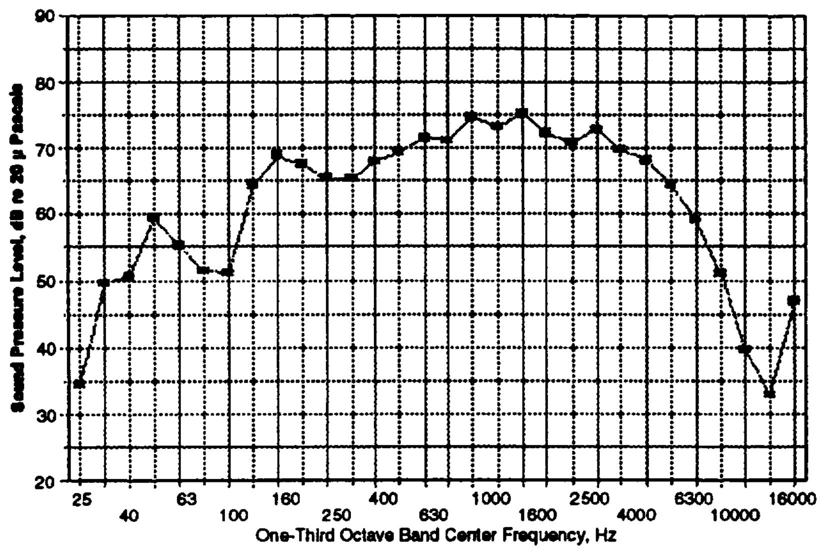

Figure 39 Test Signal 12—Boeing 757 Landing (757L).

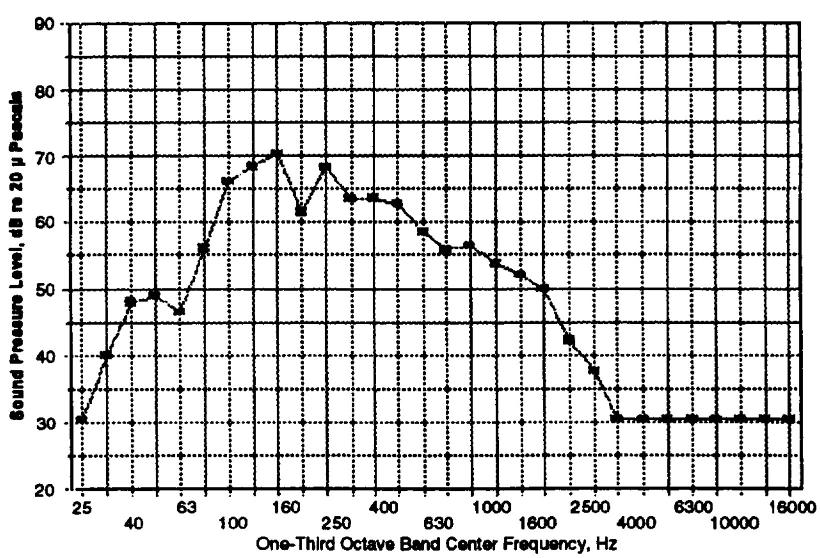

Figure 40 Test Signal 13—Boeing 757 Takeoff (757T).

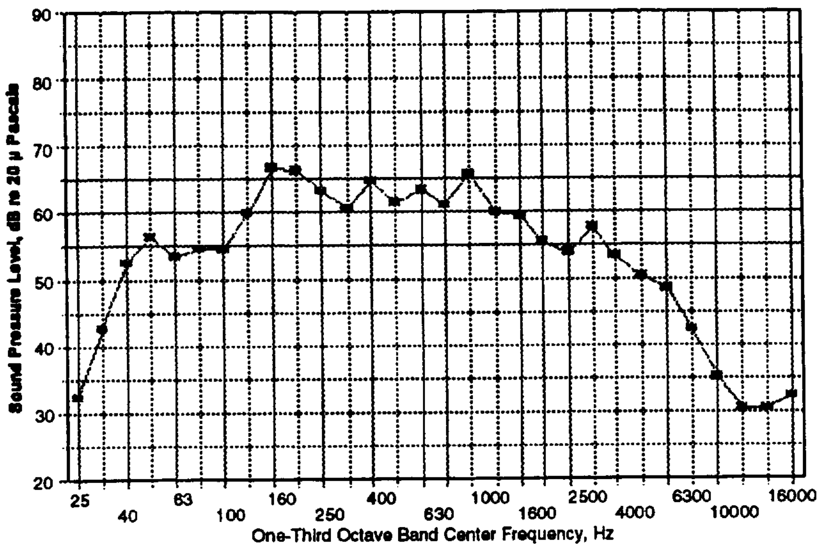

Figure 41 Test Signal 14—Boeing 767 Landing (767L).

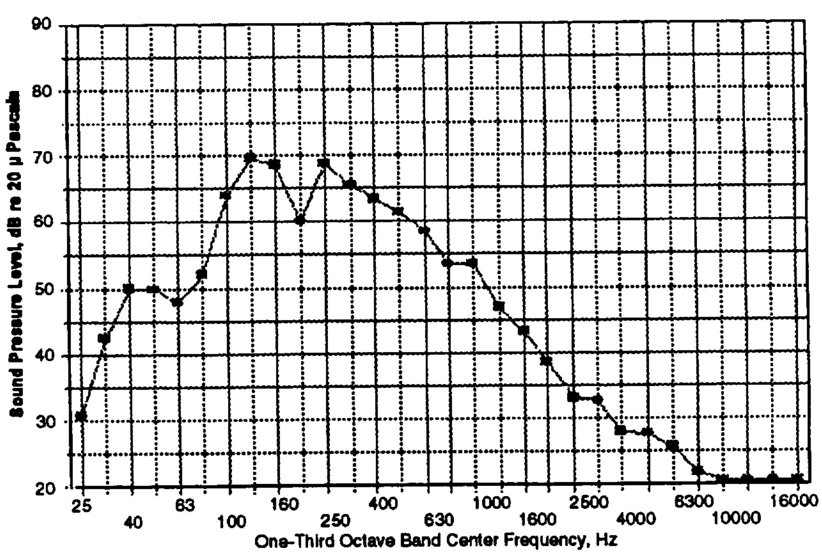

Figure 42 Test Signal 15—Boeing 767 Takeoff (767T).

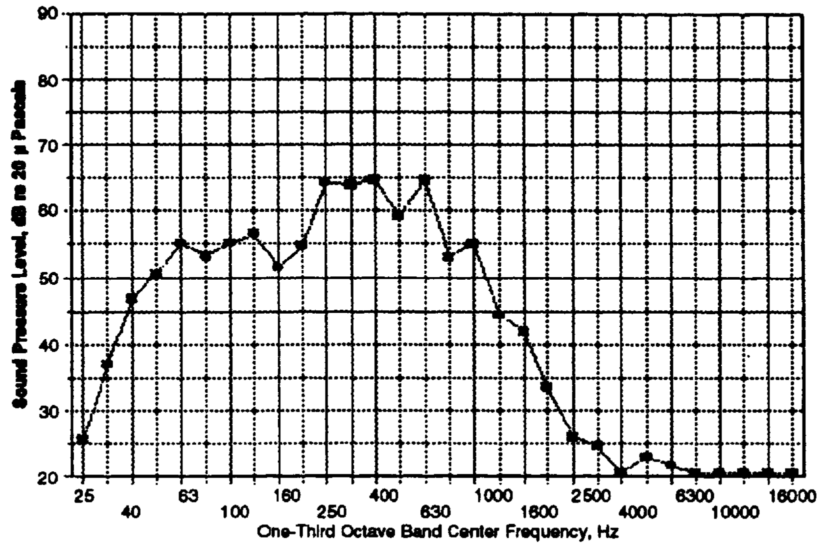

Figure 43 Test Signal 16—Boeing 777 Takeoff (777T).

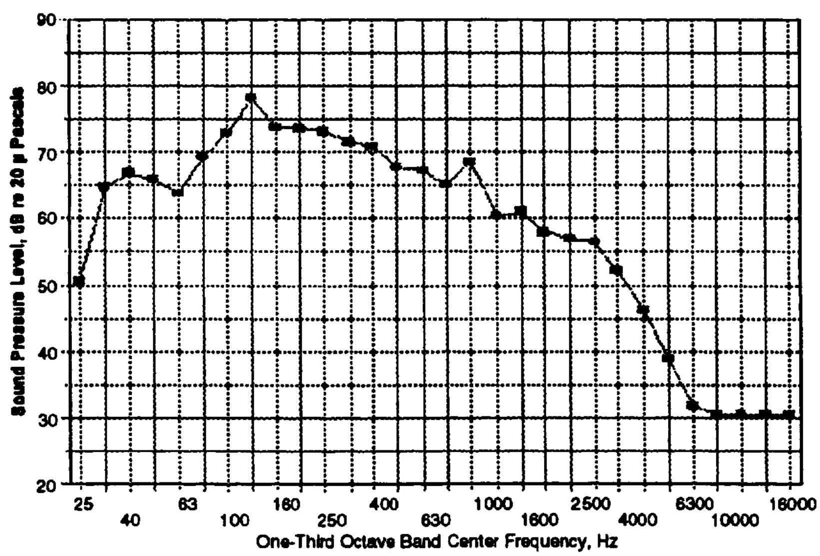

Figure 44 Test Signal 17—Boeing 777 Takeoff (777T).

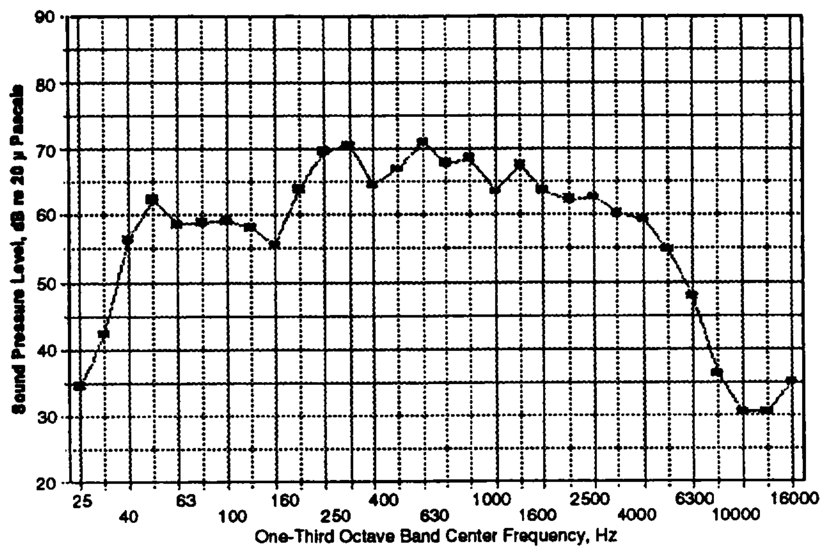

Figure 45 Test Signal 18—McDonnell Douglas DC10 Landing (D10L).

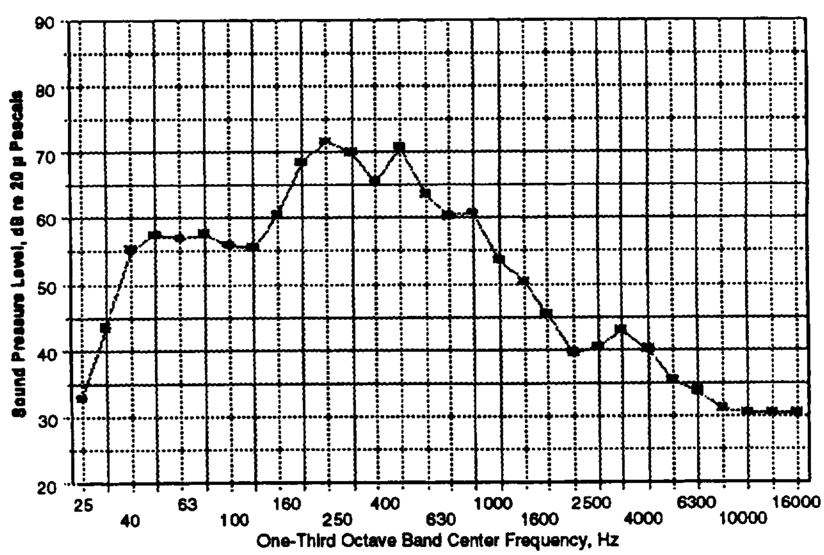

Figure 46 Test Signal 19—McDonnell Douglas DC10 Takeoff (D10T).

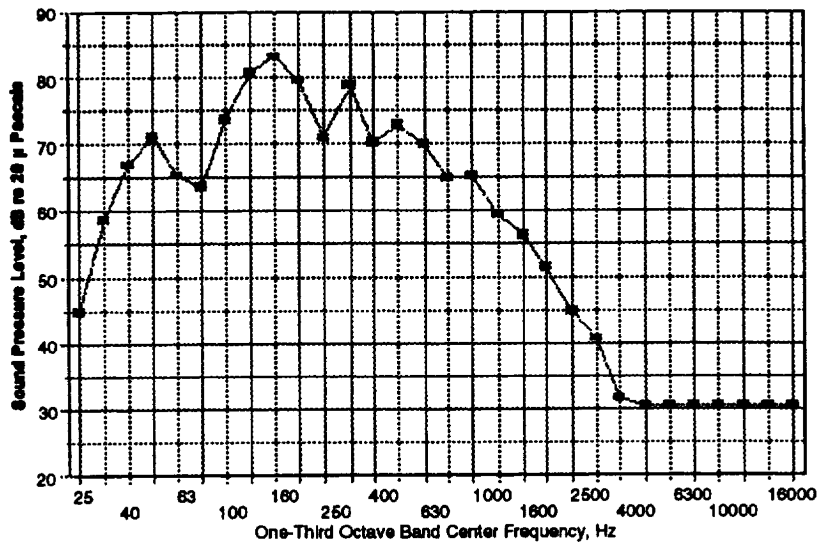

Figure 47 Test Signal 20—Douglas DC8(J) Takeoff (DC8T).

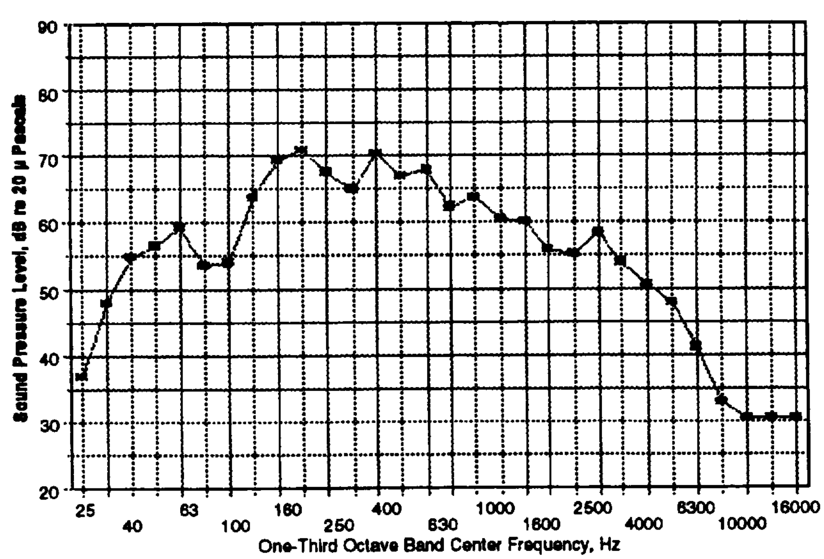

Figure 48 Test Signal 21—McDonnell Douglas MD11 Landing (M11L).

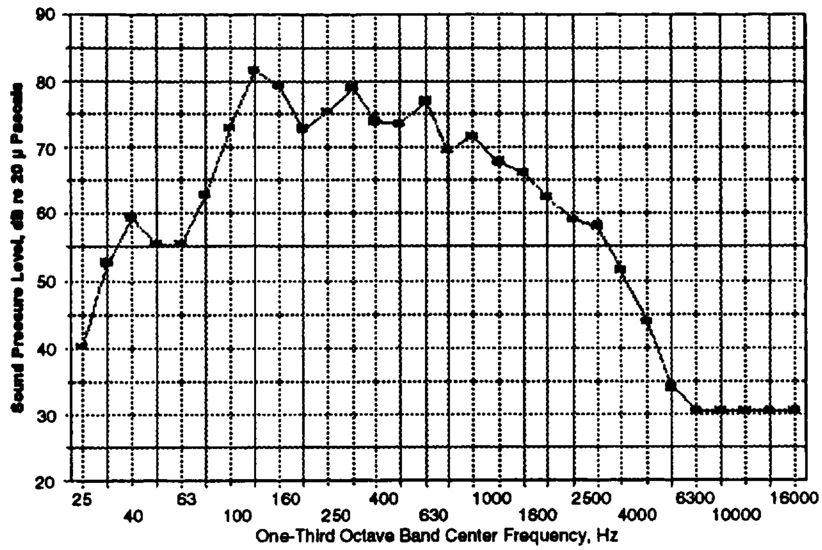

Figure 49 Test Signal 22—McDonnell Douglas MD11 Takeoff (M11T).

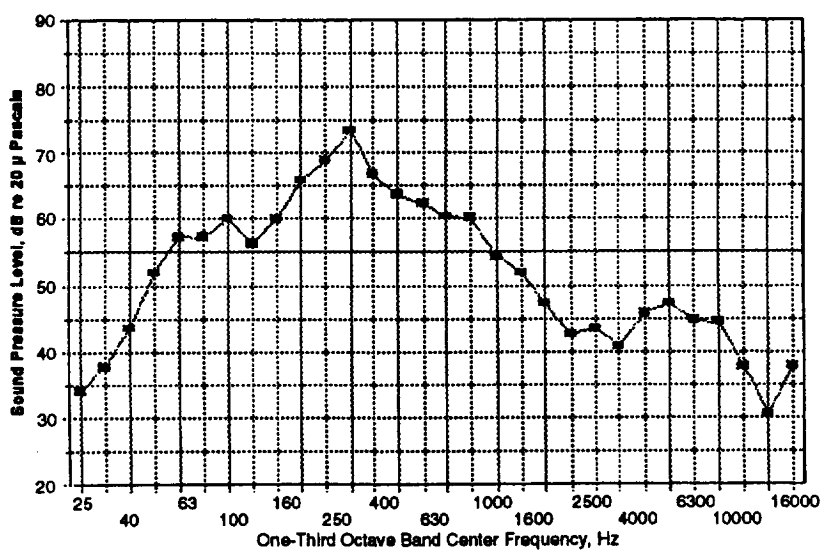

Figure 50 Test Signal 23—McDonnell Douglas MD80 Landing (M80L).

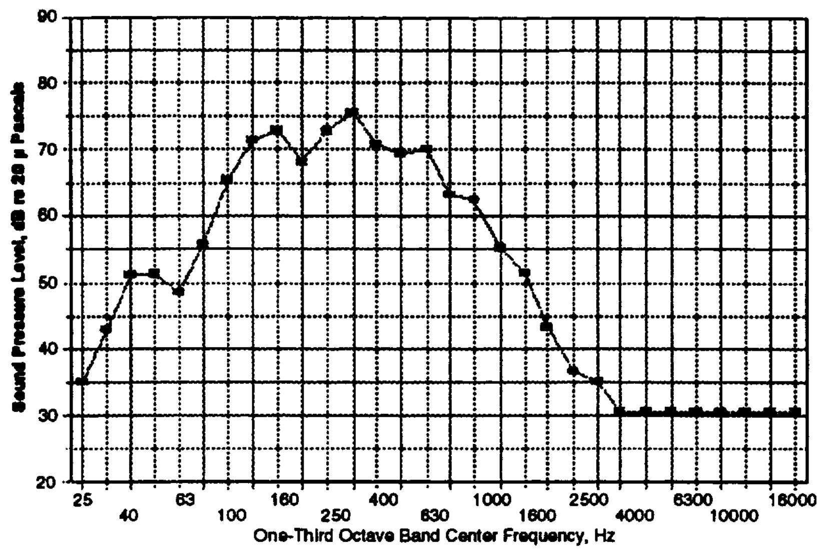

Figure 51 Test Signal 24—McDonnell Douglas MD80 Takeoff (M80T).

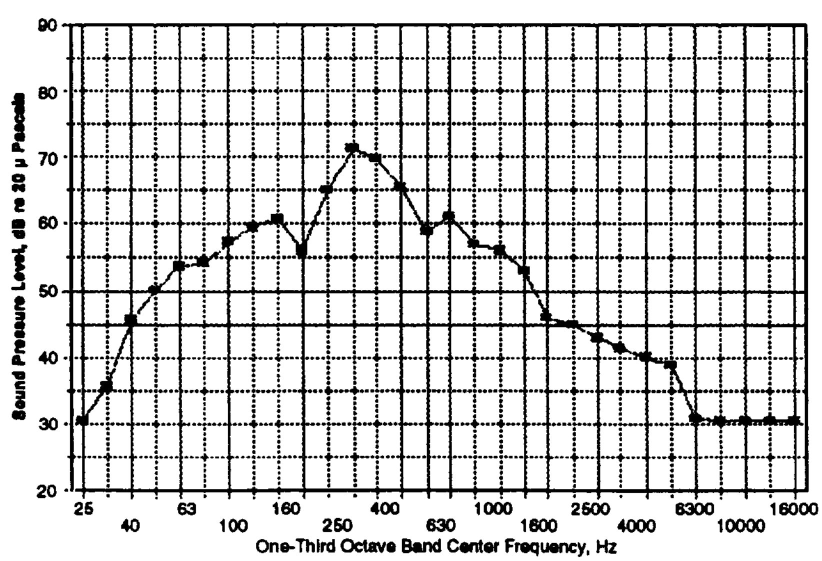

Figure 52 Test Signal 25—McDonnell Douglas MD82 Landing (M82L).

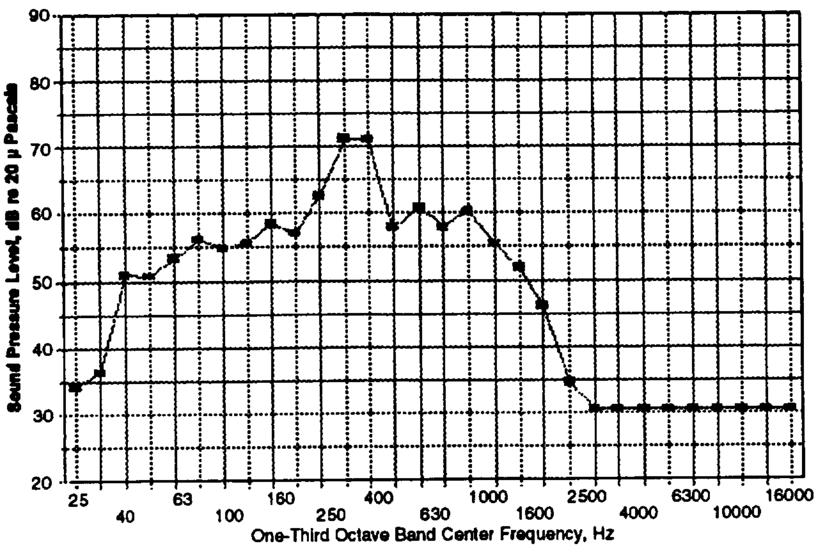

Figure 53 Test Signal 26—McDonnell Douglas MD82 Takeoff (M82T).

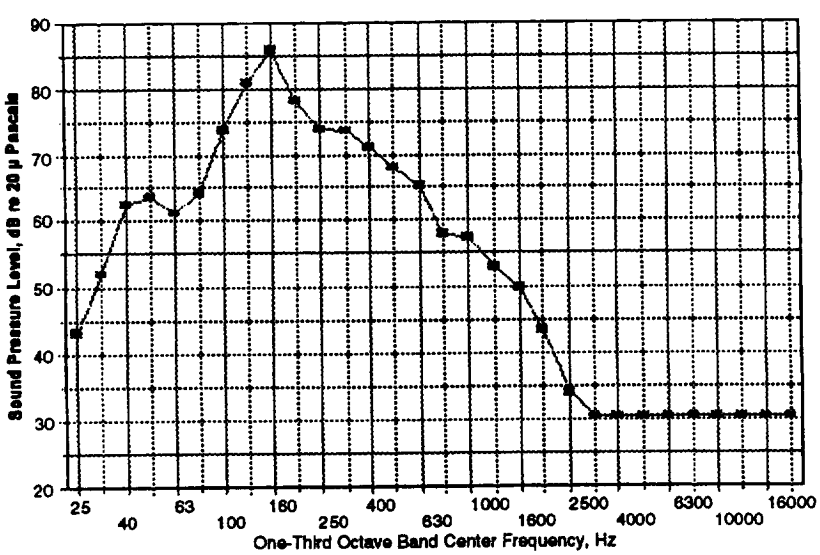

Figure 54 Test Signal 27—Simulated Aircraft Noise (short duration) (SIMT).

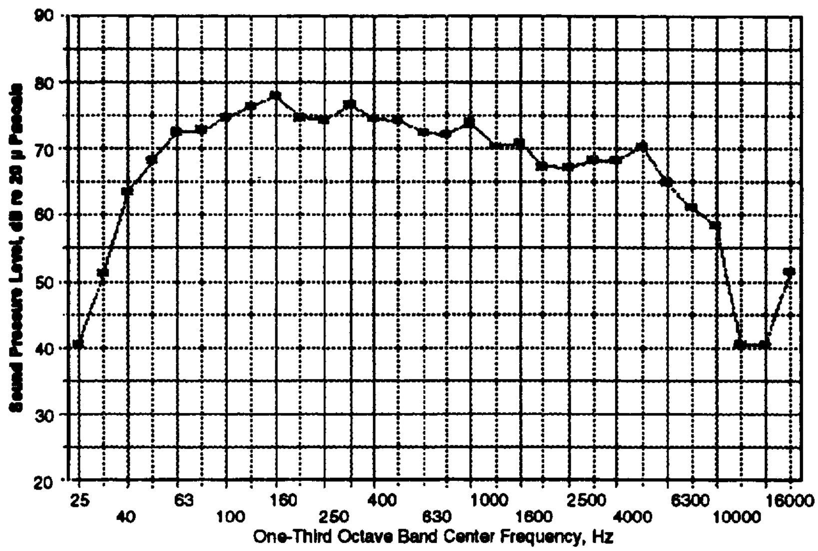

Figure 55 Test Signal 28—Simulated Aircraft Noise Stage-X Landing (ST5L).

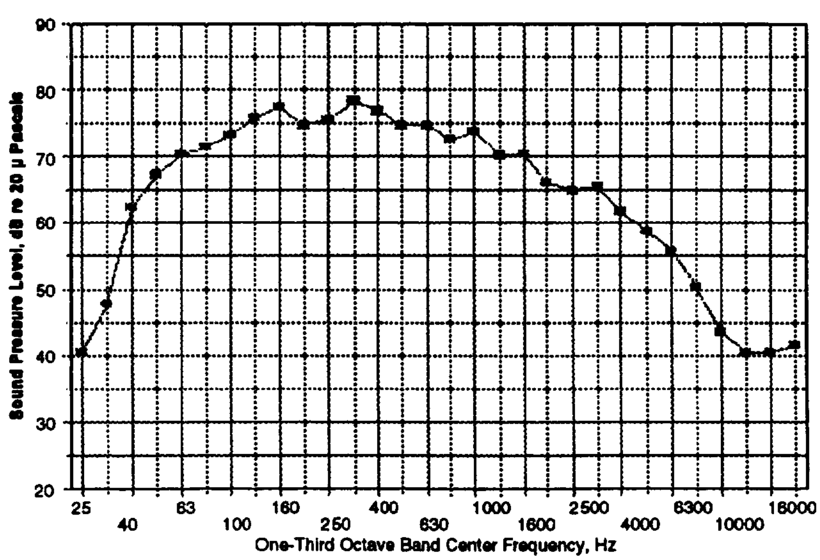

Figure 56 Test Signal 29—Simulated Aircraft Noise Stage-X Takeoff (ST6T).

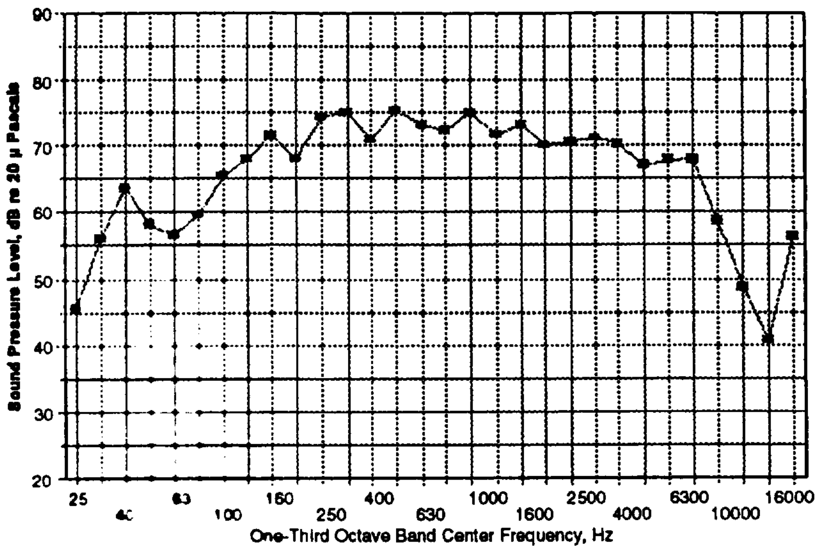

Figure 57 Test Signal 30—Boeing 707 Landing (707L).

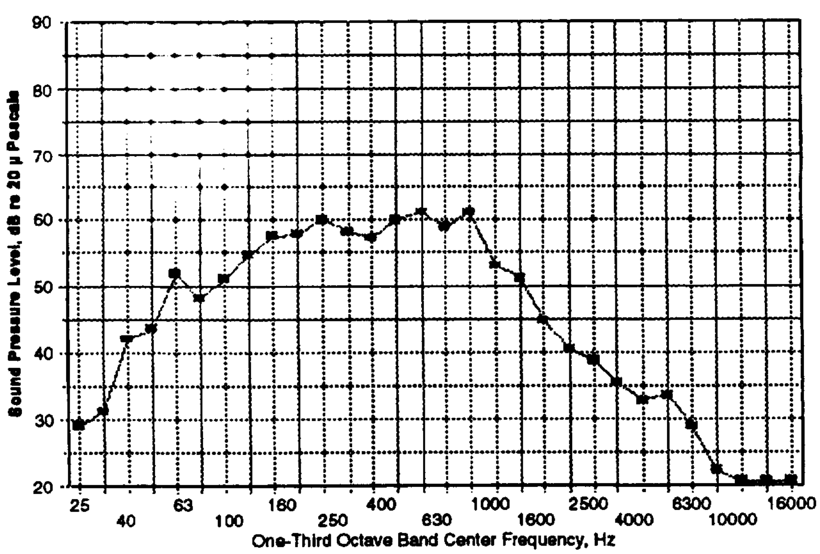

Figure 58 Test Signal 31—Automobile Passby (AUTO).

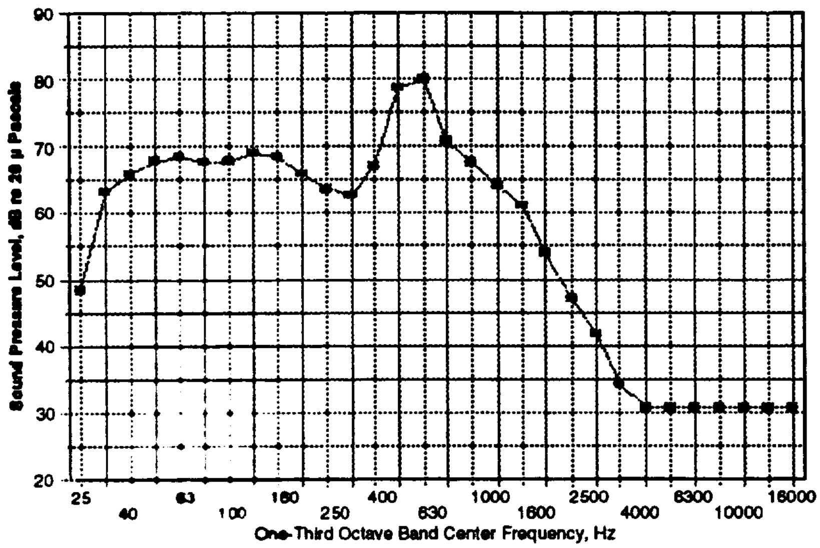

Figure 59 Test Signal 32—B1B Flyover (B1BF).

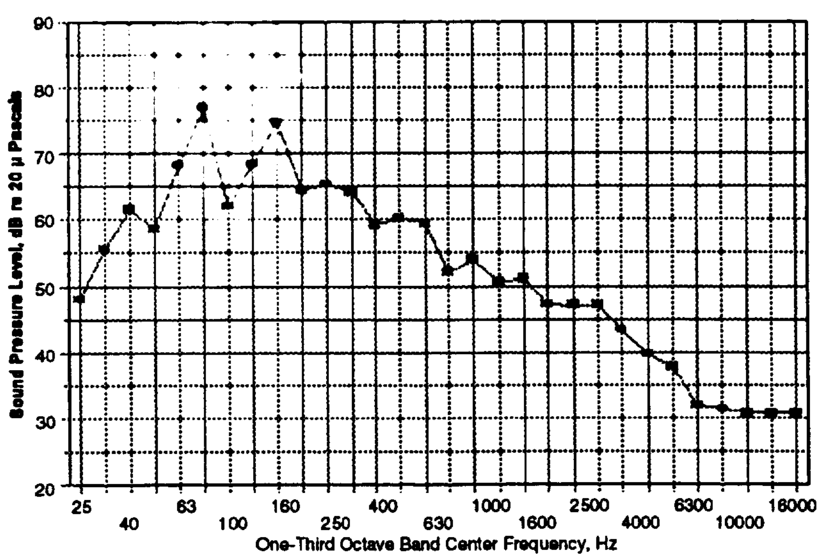

Figure 60 Test Signal 33—Douglas DC7B Landing (DC7L).

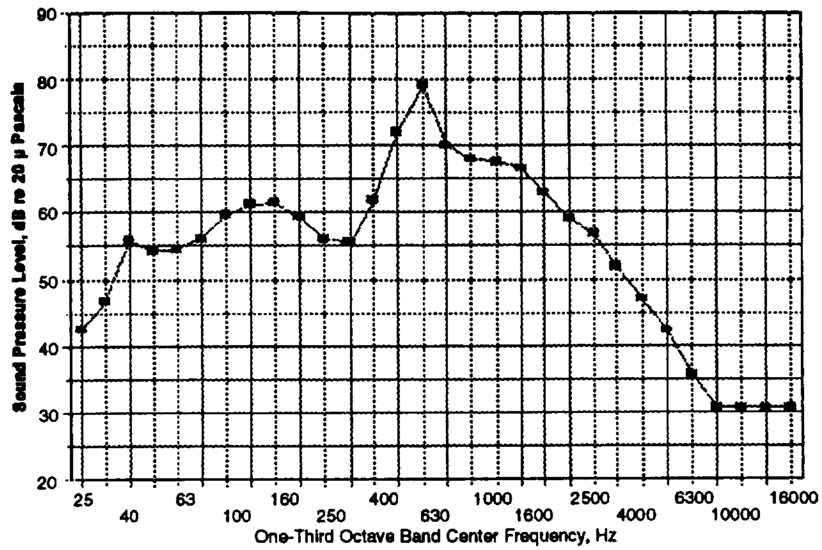

Figure 61 Test Signal 34—F111 Flyover (F11F).

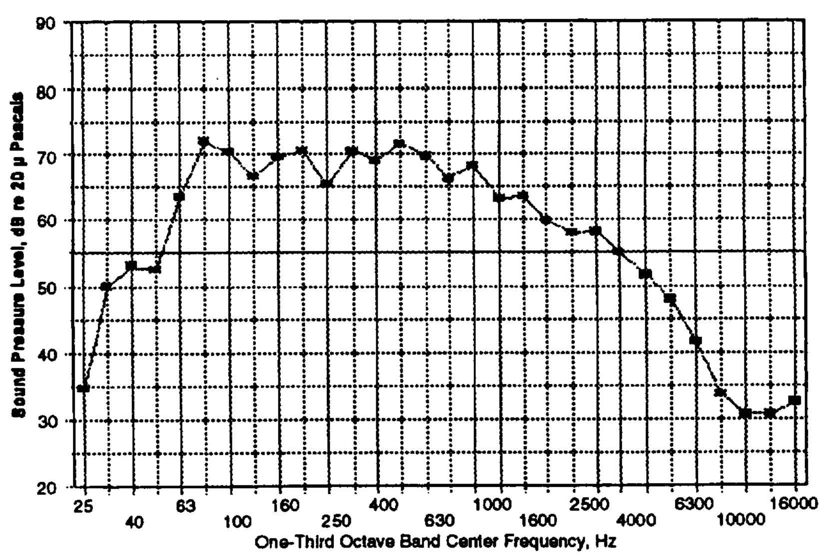

Figure 62 Test Signal 35—Train Passby (TRAN).

Table 4 One-third octave band levels of test signals at time of maximum A-level.

1/3 OB	Test Signal Identification Number										
(Hz)	1	2	3	4	5	6	7	9	10	11	12
25	40.4	35.6	32.9	35.9	35.9	28.3	30.6	30.5	34	35.6	34.5
31.5	49	43.7	47.5	46.5	46.5	42.1	41.8	40.9	47.7	47.4	49.6
40	58.7	57.2	55.5	59.4	59.4	47	46.4	46.9	56.3	52.8	50.6
50	62.4	54.5	60.6	62.2	62.2	52.7	52.7	55	58	59.2	59.4
63	62.1	56.7	61.4	63.1	63.1	52.4	55	55.2	61	60.5	55.2
80	61.8	54.2	64.1	63.4	63.4	53.2	55.4	57.2	61.1	60.2	51.4
100	62.1	65.4	68.1	62.2	62.2	52.4	58.5	55.2	59.3	59.4	51.2
125	63.1	72.4	70.8	66.2	66.2	57.2	58.8	57.1	57.4	57.5	64.4
160	61.6	75.4	70.6	68.9	68.9	53.9	58.4	59.3	59.4	68	68.9
200	56.3	72.9	67.1	74.4	74.4	60.4	54.2	60.4	64.7	74.6	67.5
250	63.8	66.4	63.9	76.1	76.1	64.8	56.9	65	69.4	75.9	65.4
315	71	75.1	68.9	82.1	82.1	69	63.6	71.2	70.6	71.7	65.3
400	72.4	71	73	76	76	63.6	67.1	65.6	62.7	66.9	68
500	69.5	71.5	73.2	73.1	73.1	57.2	66.9	63.9	69.4	66.8	69.4
630	62.7	66.3	70.9	77.5	77.5	60.8	64.3	67	68	60.6	71.5
800	64.1	64.1	58.7	70	70	53.5	60.7	58.5	64.2	58.6	71.1
1000	61.1	64	65.2	72.6	72.6	55.4	65.5	59.4	64.8	59.5	74.6
1250	62.7	60.3	59.8	68.3	68.3	50.8	57.7	53.8	63	51.3	73.2
1600	60.8	61.4	57.5	66.5	66.5	48.1	53.3	50.8	69.8	49	75.2
2000	57	60.4	52.5	60.6	60.6	40.7	46.7	44.4	60	44.1	72.3
2500	56.3	50.7	49.2	55.6	55.6	38.6	42.6	39.2	56.3	40.2	70.9
3150	60.1	50.3	48.1	52.5	52.5	29.8	43.9	34.9	59.8	40.5	72.9
4000	52.7	42.9	41.4	44.3	44.3	22.3	39.5	30.5	56.2	37	69.8
5000	50.3	34	35.9	35.6	35.6	22.3	35.2	30.5	54.4	35.3	68.1
6300	43.1	30.5	32.9	30.5	30.5	20.5	35	30.5	52.9	32.3	64.4
8000	35.5	30.5	30.5	30.5	30.5	20.5	25.5	30.5	44.1	30.5	59
10000	30.5	30.5	30.5	30.5	30.5	20.5	20.5	30.5	32.1	30.5	51
12500	30.5	30.5	30.5	30.5	30.5	20.5	20.5	30.5	30.5	30.5	39.6
16000	30.5	30.5	30.5	30.5	30.5	20.5	20.5	30.5	30.5	30.5	32.9
20000	30.5	30.5	30.5	30.5	30.5	20.5	20.5	30.5	32.3	30.5	46.8

1/3 OB	Test Signal Identification Number											
(Hz)	13	14	15	16	17	18	19	20	21	22	23	24
25	30.5	32.3	30.6	25.6	50.6	34.5	32.9	44.7	36.8	40.1	34	34.9
31.5	39.9	42.5	42.4	37	64.7	42.2	43.5	58.7	47.8	52.6	37.7	42.8
40	47.9	52.5	50	46.9	66.8	56.3	55.2	66.9	54.9	59.4	43.6	51.2
50	48.8	56.4	49.9	50.6	65.9	62.3	57.5	71	56.5	55.4	52	51.3
63	46.4	53.4	47.9	55.1	63.8	58.7	56.9	65.3	59.4	55.4	57.4	48.6
80	56	54.6	52.1	53.2	69.3	58.9	57.6	63.6	53.5	62.8	57.3	55.8
100	66.2	54.5	64	55.1	73	59.2	55.9	73.6	54	73	60.1	65.4
125	68.4	59.8	69.6	56.5	78.2	58.1	55.5	80.7	63.8	81.6	56.3	71.4
160	70.4	66.8	68.6	51.4	73.8	55.6	60.5	83.2	69.3	79.4	60	72.9
200	61.6	66.3	60.1	54.7	73.6	63.9	68.5	79.6	70.9	72.8	65.9	68.1
250	68.2	63.2	68.8	64.3	73.1	69.6	71.6	70.9	67.5	75.3	68.9	72.9
315	63.5	60.5	65.4	63.9	71.5	70.5	69.9	78.8	64.9	79	73.5	75.5
400	63.6	64.8	63.4	64.7	70.8	64.5	65.4	70.2	70.4	73.9	66.8	70.8
500	62.8	61.5	61.4	59.2	67.7	66.9	70.9	72.8	66.9	73.5	63.6	69.4
630	58.5	63.4	58.5	64.7	67.2	71.1	63.6	69.9	67.9	77	62.3	70
800	55.8	61.2	53.6	52.9	65.1	67.8	60.3	65	62.3	69.5	60.4	63.2
1000	56.4	65.9	53.6	55	68.5	68.6	60.9	65.2	63.8	71.6	60.2	62.4
1250	53.7	60	46.8	44.3	60.4	63.5	53.6	59.3	60.5	67.8	54.5	55.2
1600	52	59.5	43.1	41.9	61	67.6	50.4	56.3	60.1	66.2	52	51.5
2000	49.9	55.5	38.5	33.5	57.9	63.6	45.4	51.3	55.9	62.4	47.2	43.2
2500	42.1	53.9	33	25.9	57	62.3	39.5	44.7	55.2	59	42.5	36.5
3150	37.5	57.6	32.6	24.5	56.4	62.7	40.4	40.7	58.4	58.1	43.5	34.9
4000	30.5	53.4	27.9	20.5	52.2	60.3	42.9	31.5	53.9	51.5	40.7	30.5
5000	30.5	50.2	27.5	22.9	46.2	59.3	40	30.5	50.7	43.8	45.8	30.5
6300	30.5	48.5	25.6	21.5	38.8	54.8	35.3	30.5	47.8	34	47.3	30.5
8000	30.5	42.3	21.7	20.5	31.7	47.7	33.7	30.5	41.1	30.5	44.7	30.5
10000	30.5	35.1	20.5	20.5	30.5	36.2	31.1	30.5	32.9	30.5	44.5	30.5
12500	30.5	30.5	20.5	20.5	30.5	30.5	30.5	30.5	30.5	30.5	37.7	30.5
16000	30.5	30.5	20.5	20.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5
20000	30.5	32.3	20.5	20.5	30.5	34.9	30.5	30.5	30.5	30.5	37.7	30.5

1/3 OB (Hz)	Test Signal Identification Number										
	25	26	27	28	29	30	31	32	33	34	35
25	30.5	34	43.1	40.5	40.5	45.6	29	48.5	48	42.5	34.6
31.5	35.6	36.2	52	51.2	47.7	56.1	31.3	63.3	55.7	46.7	50
40	45.5	50.8	62.4	63.5	62.5	63.7	42	65.8	61.5	55.8	53.1
50	50.1	50.7	63.6	68.2	67.3	58.1	43.4	67.8	58.7	54.2	52.5
63	53.7	53.4	61.2	72.6	70.3	56.6	51.8	68.5	68.3	54.5	63.5
80	54.2	56.2	64.2	72.8	71.4	59.6	48.1	67.7	77	56.1	72
100	57.3	54.9	73.9	74.7	73.2	65.4	51	67.8	61.9	59.7	70.3
125	59.5	55.6	81	76.4	75.8	68	54.7	69	68.5	61.3	66.6
160	60.8	58.4	85.9	77.9	77.4	71.5	57.6	68.5	74.8	61.5	69.5
200	56	56.9	78.2	74.7	74.7	68	57.8	65.9	64.3	59.3	70.6
250	65.1	62.6	74	74.2	75.5	74.3	60	63.7	65.3	56.1	65.3
315	71.2	71.2	73.7	76.6	78.3	75	58.2	62.8	64.1	55.5	70.5
400	69.8	71.1	71.3	74.5	76.8	70.8	57.2	67.1	59.2	61.8	69
500	65.6	57.8	68.3	74.4	74.7	75.3	60	78.7	60.2	72	71.5
630	58.8	60.8	65.2	72.4	74.7	73.1	61.1	79.9	59.5	79.1	69.7
800	61.2	57.9	57.8	72.1	72.5	72.3	58.9	70.7	52.1	70.1	66.3
1000	57	60.3	57.4	73.9	73.8	75	61.2	67.6	53.9	68	68.2
1250	56.1	55.4	52.9	70.3	70.2	71.6	53	64	50.6	67.6	63.2
1600	53	51.8	49.7	70.8	70.4	73.1	51.1	61.1	51	66.7	63.5
2000	45.9	46.1	43.5	67.4	66.1	70.1	44.6	53.9	47.2	63	59.8
2500	44.9	34.5	34	67.2	65	70.5	40.5	47.1	47.1	59.1	58
3150	43	30.5	30.5	68.2	65.5	71.1	38.7	41.8	47.1	56.8	58.2
4000	41.4	30.5	30.5	68.2	61.8	70.2	35.4	34.1	43.3	51.9	55.1
5000	40	30.5	30.5	70.4	58.8	67	32.7	30.6	39.6	47	51.6
6300	38.9	30.5	30.5	64.9	55.9	67.8	33.5	30.6	37.6	42.2	47.9
8000	30.7	30.5	30.5	61.2	50.4	67.9	28.9	30.6	31.8	35.6	41.5
10000	30.5	30.5	30.5	58.5	43.5	58.6	22.2	30.6	31.2	30.6	33.6
12500	30.5	30.5	30.5	40.5	40.5	48.7	20.6	30.6	30.6	30.6	30.6
16000	30.5	30.5	30.5	40.5	40.5	40.7	20.6	30.6	30.6	30.6	30.6
20000	30.5	30.5	30.5	51.5	41.5	56.3	20.6	30.6	30.6	30.6	32.4

Table 5 Presentation levels of fixed test signals in terms of weighted metrics.

ID #	Abbr.	Duration	TAVOA	MXMOA	OASEL	TAVA	MXMA	ASEL	TAVB	MXMB	BSEL	TAVC	MXMC	CSEL	TAVD	MXMD	DSEL	TAVE	MXME	ESEL
1	101L	14.5	71.6	78	83.4	67.5	73.9	79.2	70.3	77	82	71.5	77.9	83.3	71.9	78.8	83.6	70.7	77.7	82.5
2	101T	14.5	77.1	81.9	88.9	70.3	75.4	82	75.3	80.2	87	77	81.8	88.8	75.2	80.4	87	74.4	79.5	86.2
3	727L	14.5	74	80.4	85.8	68.5	75.3	80.3	72.3	79	84	73.9	80.3	85.6	72.5	79	84.3	72	78.8	83.8
4	727T	14.5	81.8	86.9	93.6	76.1	81.6	87.8	80.2	85.8	92	81.7	86.9	93.5	80.2	85.9	92	79.7	85.3	91.5
5	72TF	30	81.8	86.9	93.6	76.1	81.6	87.8	80.2	85.8	92	81.7	86.9	93.5	80.2	85.9	92	79.7	85.3	91.5
6	732T	14	67.5	72.7	79.2	61.7	66.8	73.3	66.1	71.6	77.8	67.4	72.6	79.1	66.1	71.6	77.7	65.7	71.1	77.3
7	733L	14.5	67	73.9	78.8	63.4	70.8	75.2	65.9	73.2	77.7	66.9	73.8	78.7	66.3	73.4	78	65.9	73.3	77.7
8	733L	13.5	67.6	74.4	79.1	64	70.9	75.5	66.6	73.8	78.1	67.5	74.3	79	67.3	74.4	78.8	66.8	74	78.2
9	733T	16	70.7	75.2	82.8	64.9	70.4	77.1	69.3	74.4	81.5	70.6	75.2	82.7	69.2	74.3	81.4	68.9	74	81
10	747L	15.5	74.3	79.9	86.4	71	75.6	83	73.3	78.5	85.3	74.2	79.8	86.3	75.8	80.2	87.8	74.1	78.8	86.2
11	747T	14	75.5	80.3	87.1	67.5	72.5	79.1	73.7	78.8	85.3	75.4	80.2	87	73.4	78.5	85	72.5	77.5	84.1
12	757L	15	76.9	83.4	88.8	76.5	83.2	88.5	76.5	83	88.4	76.8	83.2	88.7	82.7	89.7	94.6	79.9	86.9	91.8
13	757T	14.5	70.7	76	82.5	63	67.6	74.8	68.5	73.6	80.3	70.6	75.9	82.4	68.3	73.3	80.1	67.4	72.3	79.2
14	767L	14.5	70.2	74.8	82	66.4	71.3	78.2	68.8	73.6	80.5	70.1	74.7	81.8	71.7	76.3	83.4	69.8	74.5	81.6
15	767T	14.5	70	75.6	81.8	61.6	66.8	73.3	67.8	73.3	79.6	69.9	75.5	81.7	67.4	72.8	79.1	66.6	72	78.3
16	777T	14.5	68	73	79.8	60.9	66.8	72.7	66.4	71.2	78.2	68	72.9	79.7	66.2	70.8	77.9	65.4	70.3	77.2
17	777T	16	79.4	83.6	91.6	70	75.6	82.2	76	80.9	88.2	79	83.4	91.2	76	81.2	88.2	74.7	79.8	86.9
18	D10L	15	74.8	81	86.7	71.3	76.8	83.2	73.7	79.9	85.6	74.6	81	86.5	76.9	83.2	88.8	75.1	81.2	87
19	D10T	14.5	74.4	78.2	86.1	67.2	72	78.9	72.6	76.8	84.3	74.2	78.1	86	72.4	76.6	84.2	71.7	75.9	83.4
20	DC8T	16.5	81.4	87.8	93.7	72.2	78.1	84.6	78.7	85.2	91	81.2	87.6	93.5	78.2	84.6	90.5	77.2	83.5	89.5
21	M11L	14.5	72.1	78.1	83.9	68.1	73.4	79.9	70.9	76.8	82.7	72	78	83.8	73	78.3	84.7	71.5	77.1	83.3
22	M11T	16	81.3	87.2	93.5	74	80.8	86.2	79	85.3	91.2	81.2	87.1	93.3	79	85.4	91.1	78	84.5	90.2
23	M80L	13.5	70.1	76.9	81.5	64.3	71.1	75.7	68.9	75.9	80.3	70	76.9	81.5	69	76	80.5	68.5	75.4	80
24	M80T	15.5	77.2	81.3	89.2	69.4	74.9	81.5	75.2	79.9	87.3	77.1	81.2	89.1	74.8	79.6	86.9	74.1	79.1	86.2
25	M82L	15	68.8	75.7	80.7	63.1	70.5	75	67.4	74.8	79.3	68.7	75.6	80.6	67.7	74.9	79.6	67.1	74.6	79
26	M82T	16	71.9	75.4	84	66.5	70.3	78.6	70.7	74.6	82.9	71.8	75.4	84	70.8	74.7	82.9	70.4	74.5	82.6
27	SIMT	9.5	83.1	88.4	93.1	71.5	76.7	81.5	80.2	85.5	90.2	82.9	88.3	92.9	79.4	84.7	89.4	78	83.3	88
28	ST5L	14.5	80.5	86.6	92.3	76.6	82.2	88.4	78.9	84.8	90.7	80.3	86.4	92.1	81.5	88.3	93.3	79.9	86.4	91.7
29	ST6T	15	82.9	86.7	94.8	78.6	82	90.5	81.5	85.2	93.4	82.8	86.6	94.7	83	86.7	94.9	81.7	85.4	93.6
30	707L	15.5	78.9	84.9	91	77.4	83.2	89.4	78.1	84.1	90.2	78.7	84.7	90.7	84.5	89.6	96.5	81.8	87.1	93.8
31	AUTO	14	59.6	69.4	71.2	56.4	66.3	68	58.7	68.6	70.3	59.5	69.4	71.2	59.1	68.9	70.7	58.6	68.4	70.2
32	B1BF	14	78.1	84	89.7	71.7	80.9	83.3	75.8	83.2	87.4	77.9	83.9	89.5	75.4	83	87	75	83.2	86.6
33	DC7L	14.5	72.8	80.4	84.5	60.5	67.3	72.3	68.1	75.8	79.9	72.3	80.1	84.1	67.8	75.1	79.5	66.3	73.8	78.1
34	F11F	12	72.8	81.3	83.8	69.8	79.7	80.8	71.7	81.1	82.7	72.7	81.3	83.7	72.7	82.1	83.7	71.9	81.5	82.9
35	TRAN	13.5	74.4	80.7	85.8	69.5	75.9	81	72.4	79	83.8	74.2	80.6	85.6	73.7	80.2	85.2	72.5	79.1	84

Table 6 Presentation levels of fixed test signals in terms of calculated metrics.

ID #	Abbr.	Duration	TAVPNL	MXMPNL	EPNL(NT)	TAVPNLT	MXMPNLT	EPNL	TAVLLZ	MXMLLZ	LLZSEL	TAVPLS	MXMPLS	PLSSEL
1	101L	14.5	78.4	85.3	90.2	80	87.2	91.8	84.8	91	96.6	70.9	77.1	82.6
2	101T	14.5	81.3	86.4	93	82.7	87.5	94.4	86.5	91.3	98.3	73.2	78.1	85
3	727L	14.5	79.2	85.5	90.9	80.9	87.4	92.7	84.8	90.8	96.6	71.2	77.1	82.9
4	727T	14.5	86.6	92.1	98.4	88.1	94	99.9	91.1	96	102.9	77.9	83.2	89.6
5	72TF	30	86.6	92.1	98.4	88.1	94	99.9	91.1	96	102.9	77.9	83.2	89.6
6	732T	14	71.7	77.3	83.3	73.2	79.1	84.8	77.5	82	89.1	64.8	69.6	76.4
7	733L	14.5	72.6	79.6	84.4	74.3	81.7	86.1	79.5	86.1	91.3	65.8	72.3	77.6
8	733L	13.5	73.9	80.7	85.4	75.3	81.8	86.8	80.8	87.2	92.2	67	73.5	78.4
9	733T	16	75.3	80.2	87.4	76.9	82.1	89.1	80.9	85.5	93.1	67.9	72.5	80.1
10	747L	15.5	82.9	87.8	94.9	84.8	90.6	96.9	88.7	93.3	100.7	74.3	78.8	86.4
11	747T	14	78.8	84	90.4	80.2	85.6	91.8	83.2	87.5	94.8	70.6	75.1	82.2
12	757L	15	88.8	95.7	100.7	89.8	96.6	101.7	92.7	99.2	104.6	78.8	85.6	90.7
13	757T	14.5	74.1	79	85.9	75.4	79.9	87.1	80.5	84.7	92.2	67.4	71.8	79.2
14	767L	14.5	78.6	83.5	90.4	80.5	85.6	92.3	85.2	89.7	97	71	75.3	82.8
15	767T	14.5	72.3	78	84.1	73.4	79	85.1	77.6	82.5	89.4	65.5	70.4	77.2
16	777T	14.5	71.2	76.2	82.9	72.9	78.2	84.7	76.7	81.3	88.4	64.1	68.6	75.9
17	777T	16	82.5	88.1	94.7	83.8	89.5	96	88.2	93.3	100.3	74.5	79.5	86.7
18	D10L	15	83.8	90.3	95.7	85.2	91.5	97.1	89.5	95.1	101.4	75.1	80.8	87
19	D10T	14.5	78.2	82.5	90	79.7	84.4	91.5	83.3	87.4	95	70.4	74.3	82.1
20	DC8T	16.5	83.8	89.7	96.1	85	91.1	97.3	88.1	93.2	100.4	75.2	80.7	87.5
21	M11L	14.5	79.6	84.9	91.4	81	86.3	92.7	86.3	91.4	98.1	72.1	77.2	83.9
22	M11T	16	85.2	91.7	97.4	86.4	93.6	98.6	90.2	96.5	102.4	76.7	82.9	88.8
23	M80L	13.5	75.8	83.3	87.2	77	84.2	88.5	81.3	87.7	92.7	68.2	74.8	79.7
24	M80T	15.5	80.1	85.3	92.1	81.3	86.5	93.4	84.5	89	96.5	72.1	76.7	84.1
25	M82L	15	74	81.2	85.9	75.4	82.2	87.3	80	86.3	91.9	66.9	73.3	78.8
26	M82T	16	76.7	80.3	88.9	77.7	81.6	89.9	82	85.2	94.2	69.2	72.4	81.4
27	SIMT	9.5	84.1	89.7	94.1	85	90.7	95	86.1	90.5	96.1	75.1	80.4	85.1
28	ST5L	14.5	88.9	95.7	100.6	90	97.1	101.7	94.3	100.5	106	79.9	86.4	91.6
29	ST6T	15	90	93.6	101.9	91	94.9	102.9	95.5	98.9	107.4	81.1	84.7	93
30	707L	15.5	90.8	96.1	102.8	93.2	97.6	105.2	94.6	100.6	106.7	80.9	86.4	92.9
31	AUTO	14	65.3	75	76.9	66.9	76.8	78.5	73.1	82.6	84.7	59.6	68.9	71.2
32	B1BF	14	81.3	89.3	93	83.2	91.6	94.8	85.9	93.2	97.5	72.8	80.3	84.5
33	DC7L	14.5	74.4	81.9	86.2	75.6	83.2	87.3	80.6	87.5	92.3	66.9	73.6	78.7

ID #	Abbr.	Duration	TAVPNL	MXMPNL	EPNL(NT)	TAVPNLT	MXMPNLT	EPNL	TAVLLZ	MXMLLZ	LLZSEL	TAVPLS	MXMPLS	PLSSEL
34	F11F	12	79.3	88.9	90.2	81.6	91.5	92.5	84.9	93	95.9	71	79.9	82
35	TRAN	13.5	80.6	87.4	92	81.9	88.6	93.3	87.3	93.5	98.8	73	79.1	84.4

APPENDIX C TABULATIONS OF AVERAGED RESULTS

Table 7 Difference between variable (727T) and fixed test signal at judged equal annoyance using weighted metrics.

ID #	TAVOA	MXMOA	OASEL	TAVA	MXMA	ASEL	TAVB	MXMB	BSEL	TAVC	MXMC	CSEL	TAVD	MXMD	DSEL	TAVE	MXME	ESEL	Signal
1	6.6	5.3	6.7	4.9	4.2	5.1	6.2	5.3	6.4	6.6	5.3	6.7	4.7	3.6	4.9	5.3	4.1	5.4	101L
2	2.0	2.3	2.1	3.0	3.6	3.2	2.1	3.0	2.3	2.0	2.3	2.1	2.3	2.9	2.4	2.5	3.2	2.6	101T
3	4.0	2.7	4.1	3.7	2.6	3.8	4.0	3.1	4.2	4.0	2.7	4.2	3.9	3.2	4.0	3.8	2.8	3.9	727L
4	0.7	0.7	0.8	0.6	0.8	0.8	0.6	0.8	0.7	0.7	0.6	0.8	0.7	0.8	0.8	0.6	0.8	0.7	727T
5	-0.4	-0.4	-0.3	-0.5	-0.3	-0.3	-0.5	-0.3	-0.4	-0.4	-0.5	-0.3	-0.4	-0.3	-0.3	-0.5	-0.3	-0.4	72TF
6	0.4	0.3	0.6	0.4	1.0	0.7	0.1	0.4	0.3	0.4	0.3	0.6	0.2	0.5	0.5	0.0	0.4	0.3	732T
7	3.4	1.6	3.5	1.2	-0.5	1.3	2.8	1.3	2.9	3.4	1.6	3.5	2.5	1.2	2.7	2.3	0.7	2.4	733L
9	-1.2	-0.6	-1.4	-1.2	-1.0	-1.5	-1.5	-0.8	-1.8	-1.2	-0.7	-1.4	-1.3	-0.6	-1.6	-1.6	-0.9	-1.8	738T
10	9.4	8.9	9.2	6.9	8.0	6.8	8.7	9.3	8.6	9.4	8.9	9.2	6.3	7.7	6.2	7.4	8.5	7.2	747L
11	-0.8	-0.5	-0.5	1.4	2.1	1.7	-0.7	0.0	-0.4	-0.8	-0.5	-0.5	-0.3	0.4	0.0	0.0	0.8	0.3	747T
12	14.3	12.9	14.3	8.9	7.9	8.8	13.0	12.3	13.0	14.3	13.0	14.3	6.9	5.7	6.9	9.1	7.9	9.1	757L
13	2.7	2.5	2.8	4.6	5.7	4.7	3.2	3.9	3.3	2.7	2.5	2.8	3.5	4.3	3.6	3.8	4.7	3.9	757T
14	10.3	10.8	10.4	8.3	9.1	8.4	10.0	11.0	10.2	10.3	10.8	10.5	7.2	8.4	7.4	8.5	9.6	8.6	767L
15	-1.0	-1.5	-0.9	1.6	2.1	1.8	-0.5	-0.2	-0.4	-1.0	-1.5	-0.9	0.0	0.4	0.2	0.2	0.6	0.4	767T
16	1.2	1.3	1.3	2.5	2.3	2.6	1.1	2.1	1.2	1.1	1.3	1.3	1.4	2.6	1.6	1.6	2.5	1.7	777T
17	2.4	3.3	2.1	6.0	6.1	5.7	4.1	5.0	3.8	2.7	3.4	2.4	4.2	4.8	3.9	4.9	5.6	4.6	777T
18	9.8	8.7	9.8	7.5	7.7	7.5	9.2	8.8	9.2	9.9	8.6	9.9	6.1	5.6	6.1	7.3	7.0	7.3	D10L
19	0.4	1.7	0.6	1.8	2.7	2.0	0.5	2.1	0.7	0.5	1.7	0.6	0.8	2.4	0.9	0.9	2.5	1.1	D10T
20	-2.2	-3.5	-2.6	1.2	1.0	0.7	-1.2	-1.9	-1.6	-2.1	-3.4	-2.5	-0.6	-1.2	-1.0	-0.2	-0.7	-0.6	DC8T
21	7.6	6.7	7.7	5.8	6.2	5.9	7.1	7.0	7.2	7.6	6.7	7.7	5.1	5.6	5.3	6.0	6.2	6.1	M11L
22	1.3	0.5	1.0	2.8	1.7	2.5	1.9	1.4	1.6	1.3	0.5	1.1	2.0	1.4	1.8	2.4	1.7	2.1	M11T
23	5.2	3.5	5.7	5.2	4.1	5.7	4.7	3.5	5.2	5.2	3.4	5.6	4.7	3.5	5.1	4.6	3.5	5.0	M80L
24	-0.1	0.9	-0.2	1.9	2.1	1.7	0.2	1.3	0.0	-0.1	0.9	-0.2	0.7	1.7	0.5	0.8	1.6	0.6	M80T
25	4.8	3.0	4.8	4.7	3.0	4.7	4.5	2.9	4.5	4.8	3.0	4.8	4.3	2.9	4.3	4.3	2.6	4.3	M82L
26	-1.1	0.5	-1.3	-1.5	0.4	-1.7	-1.6	0.3	-1.9	-1.1	0.4	-1.4	-1.6	0.3	-1.8	-1.8	-0.1	-2.1	M82T
27	-8.1	-8.3	-6.2	-2.3	-1.8	-0.4	-6.9	-6.4	-5.0	-8.0	-8.3	-6.1	-6.0	-5.5	-4.1	-5.2	-4.7	-3.3	SIMT
28	13.3	12.3	13.4	11.4	11.5	11.5	13.2	13.1	13.3	13.4	12.4	13.5	10.7	9.7	10.8	11.7	11.0	11.8	ST6L
29	11.0	12.3	11.0	9.5	11.8	9.5	10.7	12.8	10.7	11.0	12.3	11.0	9.3	11.4	9.3	10.0	12.1	10.0	ST6T
30	16.0	15.1	15.8	11.7	11.6	11.6	15.1	14.9	14.9	16.1	15.2	16.0	8.8	9.5	8.7	10.9	11.4	10.8	707L
31	1.8	-2.9	2.1	-0.8	-5.0	-0.5	1.0	-3.1	1.3	1.8	-3.0	2.0	0.7	-3.3	1.0	0.6	-3.4	0.9	AUTO
32	-1.5	-2.3	-1.2	-0.9	-4.4	-0.6	-0.9	-2.5	-0.6	-1.4	-2.3	-1.1	-0.4	-2.2	-0.1	-0.6	-3.0	-0.3	B1BF
33	-4.4	-6.9	-4.2	2.1	1.0	2.2	-1.4	-3.3	-1.3	-4.0	-6.7	-3.9	-1.0	-2.5	-0.8	-0.1	-1.8	-0.0	DC7L
34	9.0	5.6	9.9	6.2	2.0	7.1	8.4	4.8	9.3	9.0	5.5	9.9	7.5	3.9	8.4	7.7	3.9	8.6	F11F
35	8.0	6.8	8.5	7.1	6.4	7.5	8.3	7.5	8.8	8.1	6.8	8.6	7.1	6.4	7.5	7.7	6.9	8.1	TRAN

Table 8 Difference between variable (727T) and fixed test signal at judged equal annoyance using calculated metrics.

ID #	TAVPNL	MXMPNL	EPNL(NT)	TAVPNLT	MXMPNLT	EPNL	TAVLLZ	MXMLLZ	LLZSEL	TAVPLS	MXMPLS	PLSSEL	Signal
1	4.6	3.2	4.7	4.5	3.3	4.6	3.4	2.2	3.5	3.9	2.8	4.0	101L
2	2.6	3.0	2.8	2.6	3.9	2.9	2.4	2.6	2.5	2.4	2.6	2.4	101T
3	3.6	2.8	3.8	3.3	2.9	3.5	3.2	2.2	3.3	3.4	2.6	3.6	727L
4	0.9	0.8	0.9	0.8	0.9	1.0	0.8	0.9	1.0	0.9	0.9	1.1	727T
5	-0.3	-0.3	-0.2	-0.3	-0.2	-0.2	-0.1	-0.0	0.0	-0.1	-0.2	0.1	727F
6	0.7	0.6	1.0	0.6	0.8	1.0	1.1	1.8	1.5	0.8	0.9	1.0	732T
7	2.3	0.8	2.4	2.1	0.7	2.2	1.5	-0.0	1.6	2.0	0.5	2.0	733L
9	-1.3	-0.7	-1.5	-1.4	-0.6	-1.7	-0.7	-0.2	-1.0	-0.9	-0.5	-1.2	738T
10	5.8	6.4	5.7	5.3	5.5	5.2	4.3	4.7	4.3	5.7	6.5	5.5	747L
11	0.6	0.9	0.9	0.6	1.3	1.0	1.8	2.5	2.1	1.0	1.5	1.2	747T
12	7.5	6.1	7.5	8.0	7.2	8.0	6.9	5.2	6.9	8.7	7.4	8.6	757L
13	4.0	4.6	4.0	4.1	5.6	4.4	3.3	4.1	3.5	3.1	3.7	3.1	757T
14	6.7	7.3	6.8	6.3	7.2	6.4	4.9	5.4	5.1	5.9	6.7	5.9	767L
15	1.2	1.0	1.3	1.5	2.0	1.8	2.1	2.3	2.2	1.1	1.1	1.2	767T
16	2.5	3.0	2.7	2.3	3.0	2.4	3.1	3.7	3.4	2.7	3.1	2.7	777T
17	4.3	4.1	3.9	4.4	4.7	4.2	3.1	3.0	3.0	3.7	3.9	3.3	777T
18	5.8	4.8	5.7	5.8	5.5	5.9	4.3	3.6	4.4	5.8	5.4	5.7	D10L
19	1.3	2.5	1.4	1.2	2.6	1.4	1.8	2.7	2.0	1.3	2.4	1.5	D10T
20	0.2	-0.2	-0.2	0.5	0.4	0.1	0.9	0.8	0.6	0.6	0.2	0.1	DC8T
21	4.9	5.1	5.0	4.9	5.7	5.2	3.1	3.0	3.3	4.1	4.1	4.1	M11L
22	2.3	1.3	2.0	2.5	1.4	2.3	1.8	0.4	1.5	2.2	1.2	1.9	M11T
23	4.1	2.1	4.6	4.4	3.2	4.8	4.1	2.7	4.7	3.9	2.4	4.3	M80L
24	1.8	2.1	1.7	2.0	2.8	1.9	2.7	3.2	2.6	1.7	2.2	1.6	M80T
25	4.2	2.5	4.2	4.3	3.5	4.3	3.9	2.6	3.9	3.7	2.3	3.7	M82L
26	-1.3	0.6	-1.7	-0.9	1.2	-1.1	-0.7	1.2	-0.9	-1.0	0.7	-1.4	M82T
27	-4.5	-4.6	-2.6	-3.9	-3.6	-2.0	-0.9	-0.3	1.0	-3.2	-3.5	-1.4	SIMT
28	10.1	8.8	10.3	10.5	9.4	10.7	7.5	6.2	7.8	10.3	9.4	10.5	ST6L
29	9.1	10.9	9.0	9.5	11.6	9.6	6.4	7.8	6.4	9.2	11.2	9.2	ST6T
30	9.3	9.5	9.2	8.4	10.0	8.3	8.2	7.1	8.0	10.5	10.6	10.4	707L
31	0.4	-3.8	0.6	0.2	-3.7	0.6	-0.8	-5.0	-0.5	0.1	-4.2	0.3	AUTO
32	0.0	-2.5	0.2	-0.4	-2.8	-0.1	0.7	-1.5	1.1	0.7	-1.7	0.8	B18F
33	-1.6	-3.6	-1.5	-1.3	-2.9	-1.1	-1.6	-3.3	-1.3	-0.9	-2.7	-0.9	DC7L
34	7.4	3.2	8.3	6.5	2.6	7.6	6.4	3.3	7.3	7.4	3.6	8.2	F11F
35	6.7	5.4	7.2	6.9	6.2	7.4	4.6	3.3	5.0	5.9	5.0	7.0	TRAN

Table 9 Difference between variable (SIMT) and fixed test signal at judged equal annoyance using weighted metrics.

NAS	TAVOA	MXMOA	OASEL	TAVA	MXMA	ASEL	TAVB	MXMB	BSEL	TAVC	MXMC	CSEL	TAVD	MXMD	DSEL	TAVE	MXME	ESEL	Signal
1	13.9	12.9	12.1	6.6	5.2	4.9	12.4	11.0	10.7	13.9	12.9	12.1	10.0	8.3	8.3	9.9	8.1	8.1	101L
2	9.4	10.0	7.6	4.8	4.7	3.1	8.4	8.8	6.7	9.4	10.0	7.6	7.7	7.7	5.9	7.2	7.3	5.4	101T
3	10.8	9.8	9.0	4.9	3.1	3.1	9.7	8.3	8.0	10.8	9.8	9.1	8.7	7.4	6.9	7.9	6.3	6.1	727L
4	6.7	7.0	4.9	1.0	0.5	-0.7	5.5	5.2	3.7	6.7	6.9	4.9	4.7	4.2	2.9	3.9	3.5	2.1	727T
5	8.4	8.7	6.6	2.7	2.2	1.0	7.2	6.9	5.4	8.4	8.6	6.6	6.4	5.9	4.6	5.6	5.2	3.8	72TF
6	8.4	8.6	6.7	2.8	2.7	1.2	7.0	6.8	5.3	8.4	8.6	6.7	6.2	5.9	4.6	5.3	5.1	3.7	732T
7	11.1	9.6	9.3	3.3	0.9	1.5	9.4	7.4	7.6	11.1	9.6	9.3	8.2	6.3	6.5	7.3	5.1	5.5	733L
9	7.9	8.8	5.8	2.3	1.8	0.1	6.5	6.7	4.3	7.9	8.7	5.8	5.8	5.9	3.6	4.8	4.9	2.7	733T
10	16.4	16.1	14.2	8.2	8.7	6.2	14.6	14.7	12.6	16.3	16.2	14.2	11.2	12.0	9.2	11.7	12.2	9.5	747L
11	8.0	8.6	6.4	4.6	4.6	3.0	7.0	7.2	5.4	8.0	8.6	6.4	6.5	6.6	4.9	6.1	6.3	4.5	747T
12	20.3	19.2	18.4	9.3	7.6	7.3	17.9	16.7	16.0	20.3	19.3	18.4	10.9	9.1	9.0	12.4	10.6	10.5	757L
13	11.9	12.0	10.1	8.2	8.6	6.4	11.3	11.5	9.5	11.9	12.0	10.1	10.7	10.9	8.9	10.3	10.6	8.5	757T
14	15.5	16.3	13.7	7.9	8.0	6.1	14.1	14.6	12.4	15.5	16.3	13.8	10.4	11.0	8.7	11.0	11.5	9.2	767L
15	8.7	8.5	6.9	5.7	5.5	4.0	8.1	7.9	6.3	8.7	8.5	6.9	7.7	7.5	6.0	7.2	7.0	5.5	767T
16	10.5	10.9	8.7	6.2	5.3	4.4	9.3	9.8	7.5	10.4	10.9	8.7	8.7	9.3	7.0	8.2	8.5	6.4	777T
17	9.3	10.5	7.1	7.3	6.7	5.1	9.9	10.3	7.7	9.6	10.6	7.4	9.1	9.1	6.9	9.1	9.2	6.9	777T
18	18.2	17.4	16.3	10.3	9.8	8.4	16.5	15.6	14.6	18.3	17.3	16.4	12.5	11.4	10.6	13.0	12.1	11.1	D10L
19	8.4	10.0	6.7	4.2	4.4	2.5	7.4	8.5	5.7	8.5	10.0	6.7	6.8	7.8	5.0	6.2	7.2	4.5	D10T
20	6.1	5.1	3.8	3.9	3.0	1.5	6.0	4.8	3.7	6.2	5.2	3.9	5.7	4.5	3.4	5.4	4.3	3.1	DC9T
21	13.2	12.6	11.4	5.8	5.5	4.0	11.6	11.0	9.8	13.2	12.6	11.4	8.7	8.6	7.0	8.9	8.5	7.1	M11L
22	8.7	8.2	6.5	4.6	2.8	2.4	8.2	7.2	6.0	8.7	8.2	6.6	7.4	6.2	5.3	7.1	5.8	4.9	M11T
23	11.2	9.7	9.8	5.5	3.8	4.1	9.5	7.8	8.2	11.1	9.6	9.6	8.6	6.8	7.1	7.8	6.1	6.3	M80L
24	6.5	7.8	4.5	2.9	2.4	0.8	5.7	6.3	3.6	6.5	7.8	4.5	5.3	5.7	3.2	4.7	4.9	2.6	M80T
25	11.3	9.8	9.4	5.6	3.2	3.7	9.9	7.8	8.0	11.3	9.8	9.4	8.8	6.8	6.9	8.1	5.8	6.2	M82L
26	9.7	11.6	7.6	3.7	4.9	1.6	8.1	9.5	5.9	9.7	11.5	7.5	7.2	8.5	5.1	6.3	7.4	4.1	M82T
27	-0.4	-0.3	-0.4	-0.2	-0.4	-0.2	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.4	-0.3	-0.2	-0.3	-0.2	SIMT
28	17.3	16.6	15.5	9.8	9.2	8.0	16.1	15.5	14.3	17.4	16.7	15.6	12.7	11.1	10.9	13.0	11.7	11.2	STSL
29	15.8	17.4	13.9	8.7	10.3	6.8	14.4	16.0	12.5	15.8	17.4	13.9	12.1	13.6	10.2	12.1	13.6	10.2	BT6T
30	21.1	20.5	19.0	11.2	10.4	9.2	19.1	18.4	17.0	21.2	20.6	19.2	11.9	12.0	9.9	13.3	13.2	11.3	707L
31	8.3	3.9	6.7	0.1	-4.8	-1.5	6.4	1.8	4.8	8.3	3.8	6.6	5.2	0.6	3.6	4.4	-0.2	2.8	AUTO
32	9.5	9.0	7.9	4.5	0.3	2.9	9.0	6.9	7.4	9.6	9.0	8.0	8.6	6.2	7.0	7.7	4.7	6.1	B1BF

NAS	TAVOA	MXMOA	OASEL	TAVA	MXMA	ASEL	TAVB	MXMB	BSEL	TAVC	MXMC	CSEL	TAVD	MXMD	DSEL	TAVE	MXME	ESEL	Signal
33	5.9	3.7	4.2	6.8	5.0	5.0	7.8	5.4	6.0	6.3	3.9	4.5	7.3	5.2	5.6	7.5	5.2	5.7	DC7L
34	18.6	15.5	17.6	10.2	5.3	9.2	16.9	12.8	15.9	18.6	15.4	17.6	15.1	10.9	14.1	14.6	10.2	13.6	F11F
35	16.7	15.8	15.3	10.2	8.8	8.7	15.9	14.6	14.5	16.8	15.8	15.4	13.8	12.5	12.3	13.7	12.3	12.2	TRAN

Table 10 Difference between variable (SIMT) and fixed test signal at judged equal annoyance using calculated metrics.

NAS	TAVPNL	MXMPNL	EPNL(NT)	TAVPNLT	MXMPNLT	EPNL	TAVLLZ	MXMLLZ	LLZSEL	TAVPLS	MXMPLS	PLSSEL	Signal
1	8.4	7.2	6.6	7.8	6.4	6.0	3.7	2.2	1.8	6.9	5.9	5.2	101L
2	6.5	7.0	4.8	6.1	7.1	4.4	2.9	2.4	1.0	5.6	5.9	3.8	101T
3	7.0	6.3	5.3	6.3	5.5	4.5	3.1	1.5	1.2	5.9	5.3	4.2	727L
4	3.3	3.4	1.5	2.8	2.7	1.0	0.2	-0.4	-1.7	2.9	2.9	1.2	727T
5	5.0	5.1	3.2	4.5	4.4	2.7	1.6	1.0	-0.3	4.6	4.7	2.9	72TF
6	5.1	5.3	3.5	4.6	4.6	3.0	2.1	2.1	0.4	3.6	3.8	2.0	732T
7	6.6	5.3	4.8	5.9	4.4	4.1	2.3	0.1	0.4	4.8	3.4	3.0	733L
9	4.4	5.3	2.3	3.9	4.5	1.7	1.4	1.2	-0.9	3.2	3.6	1.0	733T
10	9.2	9.9	7.2	8.3	8.3	6.2	4.5	4.2	2.4	8.7	9.5	6.6	747L
11	6.0	6.4	4.4	5.6	6.0	4.0	3.5	3.6	1.8	5.2	5.9	3.6	747T
12	10.0	8.7	8.0	10.0	8.9	8.1	6.2	4.1	4.2	11.0	9.6	9.1	757L
13	9.8	10.5	8.0	9.5	10.8	7.8	5.4	5.6	3.6	7.5	8.3	5.7	757T
14	8.4	9.2	6.6	7.5	8.2	5.7	3.5	3.4	1.6	7.0	8.0	5.2	767L
15	7.5	7.5	5.7	7.4	7.7	5.7	4.7	4.2	2.8	5.7	5.8	4.0	767T
16	8.4	9.1	6.7	7.7	8.3	5.9	5.4	5.3	3.6	6.9	7.5	5.1	777L
17	7.6	7.6	5.4	7.3	7.3	5.1	3.2	2.4	1.0	6.5	6.8	4.3	777T
18	10.7	9.8	8.8	10.3	9.7	8.4	5.7	4.4	3.7	10.3	10.0	8.4	D10L
19	5.9	7.2	4.1	5.4	6.5	3.6	2.8	3.1	1.0	4.7	6.0	3.0	D10T
20	5.0	4.8	2.7	4.9	4.5	2.6	2.2	1.4	-0.2	4.6	4.3	2.3	DC9T
21	7.0	7.3	5.2	6.6	7.1	4.9	2.0	1.3	0.1	5.5	5.6	3.7	M11L
22	6.2	5.3	4.0	6.0	4.6	3.8	2.4	0.4	0.1	5.6	4.7	3.5	M11T
23	6.5	4.8	5.1	6.4	5.0	4.9	3.2	1.2	1.7	5.4	4.0	3.9	M80L
24	4.9	5.3	2.9	4.7	5.3	2.6	2.4	2.3	0.3	3.9	4.5	1.9	M80T
25	7.3	5.7	5.4	6.9	5.9	5.0	3.6	1.7	1.6	5.6	4.3	3.7	M82L
26	6.1	8.2	3.9	6.1	8.0	3.9	3.0	4.2	0.7	4.8	6.7	2.6	M82T
27	-0.2	-0.1	-0.2	-0.0	0.0	-0.0	-0.1	-0.1	-0.2	-0.1	-0.2	-0.1	SIMT

NAS	TAVPNL	MXMPNL	EPNL(NT)	TAVPNLT	MXMPNLT	EPNL	TAVLLZ	MXMLLZ	LLZSEL	TAVPLS	MXMPLS	PLSSEL	Signal
28	10.4	9.2	8.7	10.3	9.0	8.6	5.2	3.3	3.4	10.4	9.4	8.7	STBL
29	10.2	12.2	8.3	10.3	12.1	8.4	4.8	5.7	2.8	10.2	12.0	8.3	ST6T
30	10.7	11.0	8.7	9.4	10.7	7.4	6.7	5.1	4.5	11.8	11.8	9.8	707L
31	2.9	-0.9	1.3	2.4	-1.6	0.8	-1.3	-6.2	-3.0	1.1	-3.2	-0.5	AUTO
32	7.6	5.2	5.9	6.7	4.1	5.1	4.4	1.5	2.7	7.2	4.9	5.5	B1BF
33	5.3	3.6	3.5	5.2	3.4	3.5	1.7	-0.8	-0.1	4.3	2.7	2.5	DC7L
34	13.5	9.5	12.6	12.2	8.1	11.3	8.9	5.1	7.8	12.8	9.2	11.8	F11F
35	11.9	10.8	10.5	11.7	10.7	10.3	6.2	4.4	4.6	10.5	9.7	9.1	TRAN

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13. ABSTRACT (*Maximum 200 words*)

Thirty audiometrically screened test participants judged the relative annoyance of two comparison (variable level) and thirty-four standard (fixed level) signals in an adaptive paired comparison psychoacoustic study. The signal ensemble included both FAR Part 36 Stage II and III aircraft overflights, as well as synthesized aircraft noise signatures and other non-aircraft signals. All test signals were presented for judgment as heard indoors, in the presence of continuous background noise, under free-field listening conditions in an anechoic chamber. Analyses of the performance of 30 noise metrics as predictors of these annoyance judgments confirmed that the more complex metrics were generally more accurate and precise predictors than the simpler methods. EPNL was somewhat less accurate and precise as a predictor of the annoyance judgments than a duration-adjusted variant of Zwicker's Loudness Level.

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